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PREFACE

This book has been written to meet the requirements of the students who are preparing for B Sc pass or SECOND YEAR AND THIRD YEAR of the Three Year Degree course examinations. This book is a modest attempt to present the experimental procedure in the most simple and lucid style. Students will find the treatment helpful in the present day laboratory conditions. The treatment is neither too voluminous nor too brief. The book possesses the following special features:

1. A large number of self explanatory diagrams incorporating all physical principles are included. An elaborate description of the apparatus has been given to facilitate easy manipulation with a view to make an allowance for various types of instruments used for the same experiment in different laboratories.

2. Necessary and sufficient theory concerning the intelligent performance of an experiment has been given.

3. Method has been described in such a great detail and with such clarity that a student will find it very simple to do the experiment. Detailed description will enable him to fully grasp the intricacies of an experiment.

4. Clear and systematic tables have been drawn to take various observations.

5. At the graduation stage students are expected to fully know the various errors made in doing an experiment. Keeping this fact in view, precautions and sources of error have been dealt with in details. Thorough and exhaustive criticism has been added to enable a student to know the process by which percentage accuracy can be increased.

6. Oral questions in the form of an exercise has been added at the end of each experiment. It is to ascertain whether the experiment has been completely understood.

Before beginning any experiment students are advised to study carefully the introduction.

We are very much thankful to Prof. D.L. Jain, Prof. Behari Lal, Prof. D. T. Chandwani and Prof. T.N. Bhatnagar, for giving valuable suggestions in the preparation of this book. Our thanks are also due to our publishers Ramesh Book Depot and the printers, for bringing out this book in such a short time. Suggestions towards the improvement of this book will be highly appreciated.

**), 1953

Authors

PART II

PART I

(For II Year)

INTRODUCTION

Laboratory is the most important place for a student of science. It is the place where he verifies the validity of various laws governing the physical phenomenon. This requires preseverence, keen observation and accurate measurements. Physics is a science of measurements. Hence, more accurate the measurement of various entities, the nearer the truth will be the result.

For measuring various quantities, selection of proper units is essential. Three quantities are fundamental. (i) Length, (ii) Mass and (iii) Time. They are independent of each other. All other quantities can be expressed in terms of these three, cited above. For example, if we know the length of a box in three perpendicular directions, its volume can be determined. Thus, it is neither necessary nor convenient to select independent unit for each quantity. In C. G. S. system, *the unit of length is a cm., of mass a gm. and of time a second.* The respective units for these quantities in F. P. S. system are *foot, pound and second.* Temperature readings also involve the measurement of length of the mercury thread, which is proportional to the rise in temperature. It is expressed in *degree Centigrade* or *Fahrenheit.* All other units which can be expressed in terms of the fundamental units are known as *derived units.*

Measurement of length :—The simplest and the most common way of measuring length is by the help of a metre scale or an ordinary foot rule. The accuracy obtained in such measurements is extremely limited. They can measure up to only *1 mm.* or *0·5 mm.* For attaining greater accuracy *vernier scales, (screw gauges and spherometers etc.)* are to be employed. They can measure lengths accurately up to *0·001* to *·0005 cm.* depending upon their least counts.

Measurement of mass :—Mass can be measured with the help of a *balance.* The accuracy of mass determination will depend upon the *sensitivity of the balance used.* Ordinarily, by an ordinary physical balance masses up to one milligram can be measured. A *chemical balance* using a rider can be used to measure masses correct up to 0·1 milligram. Where much accuracy is not needed, a *spring balance* can also be employed for this purpose.

Measurement of time :—Generally, time is measured wit[h] help of *stop-clocks or stop-watches.* They can ordinarily measure correct up to 1 to 1/10th of a second, depending upon their least co[unt]. Specially made pocket stop watches can measure time, even u[p] 1/50th or 1/100th of a second. Time can also be measured with the [help] of a *metronome*, or a *tuning fork*. Where high accuracy is to [be] obtained, *chronometers* are used.

Getting ready for an experiment :—Before you begin a[n] experiment, thoroughly study the principle involved in it. At [the] B. Sc. stage the performonce should not be at all mechanical. It [is] almost a sheer wastage of time to perform an experiment without t[he] exact grasp of its full details. After knowing the procedure, careful[ly] study the formula which is going to be used for calculating the resul[t]. From the formula find out the quantities which are to be measure[d]. Knowing the quantities, determine the accuracy with which eac[h] quantity is to be measured. Accordingly select the apparatu[s] possessing the proper range.

Absolute error and proportional error :—In measuring any quantity, it is the *relative error* which is more important than the *absolute error*. The proportional error can be determined by taking the ratio of the magnitude of the error to the total magnitude of the quantity which is to be measured. More importance should be attached to reduce this proportional error present in the measurement of each quantity. As for example, in determining η by dynamical method, radius of the wire r should be measured more accurately than the length of the wire. Suppose an error of '2 cm. has been made in determining the length of the wire which is say, 300 cm. Then the *percentage error* committed in measuring this length will be equal to 0'065%. But a mistake of 0'002 cm. done in measuring the diameter of a wire which is say, 0'1 cm. will be 2%. Furthermore, the radius is to be raised to the fourth power in the formula, this error consequently becomes 8%. *Though the absolute error made in the determination of r is much less than the error made in determining l the percentage error in the former case is quite large.* It is altogether useless to measure one quantity more accurately, when there is present a considerable error in the measurement of other quantities. The final percentage error is the resultant effect of the errors present in measuring the various quantities involved. *Thus, the final result will not possess an accuracy greater than that possessed by the least accurately determined quantity.* Similarly, in determining acceleration

due to gravity by simple pendulum, the periodic time should determined more accurately than the length of the pendulum. A num of such examples can be cited.

Thus, first of all determine the *probable percentage e* in the measurement of each quantity, and then decide which quan are be measured to *which accuracy*. All the quantities must measured to the same degree of accuracy. The quantities w involve greater percentage error should be measured for a numbe times, and precision instruments should be used to measure them, *that the percentage error is reduced to the same value in all* quantities measured.

Calculation of percentage error:—In order to determine percentage error, take the logarithm of the quantity to be deterr in terms of the quantities to be measured, and differentiate. substitute proper values for the entities occuring in this equ and calculate the percentage error. Suppose the volume cylinder is to be measured. Then, $V = \frac{\pi}{4} D^2 l$, where V is the vol D the diameter and l the length of the cylinder. Taking logs we

$$\log V = \log \frac{\pi}{4} + 2 \log D + \log l$$

Differentiating this equation we get,

$$\frac{dv}{V} = 2\frac{\delta D}{D} + \frac{\delta l}{l}$$

We are using a vernier callipers to measure the diameter an length of the cylinder. An error of one division can be mad read ng the vernier on either side of actual coincidence Hence, the probable error may be $=0.02$ cm., when the least count of the in ment is 0.01 cm. Therefore $\delta D = 0{\cdot}02$ cm; and $\delta l = 0{\cdot}02$ cm. If l cm. and $D = 2$ cm; we have,

$$\frac{dv}{V} = 2\frac{{\cdot}02}{2} + \frac{{\cdot}02}{20}$$

dv is the error made in V, therefore the percen error will be.

$$100 \times \frac{dv}{V} = \frac{2}{2} \times {\cdot}02 \times 100 + \frac{{\cdot}02}{20} \times 100$$
$$= 2 + {\cdot}1$$
$$= 2{\cdot}1 \qquad \ldots$$

Hence the percentage error in determining the volume =2·1 As is evident, the percentage error is quite large in the measurement of diameter. Therefore, more observations should be taken to measure D, and a vernier of smaller least count should be used.

Personal errors made in taking observation:—The accuracy of the result of a depends upon *the individual performing the experiment.* As for example, suppose two different persons are to set the prism in the minimum deviation position. As they possess different powers of judgement, the setting may be slightly different, and the values obtained by the two persons for the angle of minimum deviation may differ. Even the two observations taken by the same person may differ. *Therefore, this personal factor introduces some error.* To minimise this error, observations for the same measurement are *repeated a number of times.* Arithmatic mean is then determined. Even this arithmatic mean is not completely *free from* errors. To further reduce the error, it is actually calculated. From *Gaussian theory of errors we get*,

$$E = \cdot 6745 \sqrt{\frac{\Sigma \delta^2}{n\,(n-1)}}.$$

Where E is the probable error present in the mean value M, δ the departure of each observation from the mean M, and n the number of observations taken for the same quantity. Then, the corrected value of M will be, M $\pm$ E.

Performance and recording of an experiment:—(1) Having learnt all about the experiment, select the apparatus of proper range and get it issued. Before you start doing the experiment, see that the following things are recorded in your practical note book.

(a) : Day and date.

(b) Temperature and pressure. (If they are needed)

(c) Name of the experiment.

(d) Apparatus required.

(e) A neat and carefully drawn self-explanatory diagram.

(f) Necessary theory.

(g) Method (It should be written in details, so that the revision of the experiment at some latter date may be easy.)

(h) Observation table (Always

of the page after leaving margin.)

(i) Results. (Always mention the units otherwise result will be meaning less.)

(j) Precautions and sources of error.

(k) Percentage error

(l) Criticism on the result and performance of the experiment.

2. Note the least count and the range of the instruments you are working with. Keep it in mind that small quantities and that too occuring in higher powers always need greatest attention and repetition. Very large quantities may be measured only once e. g weighing is mostly accurate and so it is done only once.

3. Note all the observations *directly* in the table. Over writing should never be done on any grounds. It is a wrong practice to note observations first in rough note book and then to record in fair note book, which give correct result. If you record a wrong set of observations and if you can explain what mistake you have made, it goes to your credit. Take as large a number of observations as possible. All quantities must be recorded with proper units.

4. As soon as you take a good number of sets of observations, start calculating the result by log tables. It is essential in the B.Sc., classes that the result must be calculated by log tables. You are already familiar with the use of log tables. All the calculations must be shown in the fair note book. It is advised to record the calculations performed by logs on the margin of the left side page. See that neatness of the copy is maintained.

5. Do not forget to mention the units of the result obtained.

6. At the end of the experiment you must discuss the result obtained, and the difficulties encountered while doing the experiment. Now calculate the percentage error, and give a fair criticism of the work you have done.

Graphs:—(1) A graph can be drawn in any two interdependent quantities e. g. between angle of incidence and angle of deviation, or between the actual readings of an ammeter or a voltmeter and corresponding errors.

2. A graph paper is required for drawing a graph. The horizontal axis is taken as X axis, and the vertical axis as Y axis.

3. The independent variable is generally plotted on the X axis and the resultant variable on the Y axis.

4. Choose a suitable scale to represent the two variables so that the full graph paper may be used.

5. The origin of the graph need not be zero.

6. Take atleast *five* observations *covering the full range*.

7. The points on graph should *preferably* be shown as $\odot$.

7. When you want to connect these points by means of a curve try to do it in a smooth way. It is not necessary for your curve to pass through all the points. Draw it smoothly in a such a way that it passes through maximum number of points.

9. It is always better to anticipate from theory whether you expect a straight line, or a hyperbolic curve etc. and draw it accordingly.

EXPERIMENT No. 1

Experiment:—To determine Young's modulus of a bar (rectangular beam) by bending (flexture).

Apparatus—A bar of rectangular cross-section, two strong knife edges placed on clamps, a scale pan or a load hanger, 6 to 8 weights of half kilo gm. each, a metre scale, a vernier-callipers, a screw gauge, a travelling microscope, a needle or a pin or a spherometer, a galvanometer, cell, key, connecting wires etc.

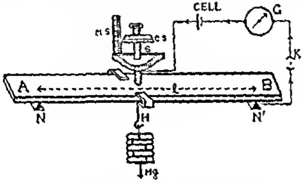

Fig. 1

Description of the apparatus—It consists of rectangular bar AB of the material whose Youngs' modulus (Y) is to be determined. The bar is placed on two rigid knife edges N and N' clamped on the table. From the mid point of the bar a hanger is suspended which can carry the load as shown in fig. (1) If microscope is to be used, there is placed a frame at the centre of the bar in which is fixed a horizontal wire as shown in fig. 5. The wire serves as a reference.

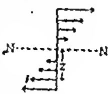

Fig. 2

When a spherometer is used to find out the depression, the arrangement is as shown in fig. (1). AB is the bar placed on the knife edges N and N'. It carries a load hanger suspended from its middle point. Just above the middle point is placed, either a micrometer screw or a sphero meter. The central leg of the spherometer should touch the middle point where the hanger is placed. An electric circuit is also made connec

$$e=\frac{Mgl^3}{3YI}.$$

For a rectangular beam $I=\frac{bd^3}{12}$, *where b and d is respectively the breadth and depth of the beam.*

$$\therefore\ e=\frac{4Mgl^3}{Ybd^3}\ \text{.........(1)}$$

When the beam is placed on the knife edges and loaded in the middle as is done in this experiment the reaction at each knife edge will be $Mg/_2$ acting in the upward direction. As in the neighbourhood of the middle point the beam will be horizontal; it may be considered as equivalent to two inverted cantilevers fixed at the middle point and loaded at C and D as shown in fig. (6). *The load $Mg/_2$ acts upwards at C and D.* Hence the depression can be obtained by formula (1) by substituting $Mg/_2$ in place of Mg and $l/_2$ in place of l. *Here l is length of the bar between the two knife edges C and D.*

$$\therefore\ e=\frac{4\frac{Mg}{2}(l/_2)^3}{Ybd^3}.$$

$$=\frac{Mgl^3}{4Ybd^3}\text{.........(2)}$$

$$\text{or } Y=\frac{Mgl^3}{4bd^3e}\text{...........(3)}$$

Method —1. Place the rectangular bar on the two knife edges symmetrically. *The two end portions of the bar which remain projecting beyond the knife edges should be equal.* Place the bar in such a way that the depth remains vertical and its length is perpendicular to the two knife edges.

Determination of depression (e) a by microscope—

2. Mark the middle point of the bar and put a frame there. The frame has a horizontal wire fixed at its centre. The wire is used to determine depression. A pin can also be fixed in place of the wire.

3. Suspend the load hanger from the middle point of the bar. Find V. C. of the microscope. Focus it (so that its scale remains vertical) on the wire or the tip of the vertical pin. Take the reading on the microscope scale. It constitutes the initial reading. In this case the horizontal cross wires should coincide with the image of the wire

4. Place gently half kilo-gm. weight on the hanger. The wire will be slightly depressed. Lower the microscope and again focus it on the wire. Again read the microscope scale. It forms the second reading.

5. Go on increasing the weights in steps of half kilo gm. Each time after focussing the microscope in a similar way note the reading on its scale. The weights can be put up to 3 to 4 kilo-gm. [*If you put more weights the elastic limit may be crossed and the beam may not return to its original condition. The depression produced should not exceed two-thirds of the maximum permissible depression, within the elastic limit. The depression should be so small that the ends at the edges may be regarded as horizontal*].

6. Now decrease the load again in steps of half kilo-gm. Each time focus the microscope and take the corresponding reading, till the weight in the hanger is again zero.

7. Find the mean reading corresponding to each load.

Determination of depression by a spherometer:—

8. In this case first of all determine the least count of the spherometer and put it on the bar in such a way, that its central screw just touches the middle point of the bar where the hanger is placed.

9. Make the electric circuit as shown in fig. (1). The galvanometer will give deflection (or the bulb will be lighted up) only when the circuit is completed i. e. when the central leg just touches the bar. Therefore, move the screw till you just get deflection. Use of voltmeter is recommended in place of galvanometer. Galvanometer is to be used with heavy resistance in series.

10. Take the reading of the spherometer in this position when there is no weight in the hanger. It will constitute first reading.

11. Now put half kilo-gm. weight in the hanger as before, the bar will be depressed. Contact between the central leg and the bar will be broken. Consequently the current will stop. Move the central leg till it just touches the bar which will be indicated by the deflection in the galvanometer. Take the reading of the spherometer. This will be the second reading.

12. As done in the previous case go on increasing the weights in steps of half kilo-gm. Each time move the central leg till it just touches the bar as before. Take corresponding readings of the spherometer.

13. Similarly decrease the load again in steps of half kilogm. as before, and take the corresponding necessary reading till the weight in the hanger is again reduced to zero.

14. Similarly determine the mean reading corresponding to each load.

15. For both the cases discussed above, determine depression for two kilo-gm. This can be done by subtracting second reading from the sixth, or 3rd from 7th and so on. Determine mean depression for two kilo-gm.

16. Measure the distance between the two knife edges C and D. It gives l.

17. Measure breadth (b) of the bar with the help of a vernier callipers. Do it at two to three places and then find out mean (b).

18. Determine the thickness (d) of the bar with the help of a screw guage, d should be determined at least at eight different places on the bar. Determine mean thickness d.

19. Knowing all the necessary things calculate Y by formule (3).

Note:—Some times the depression is determined by a optical lever. It is an extremely accurate method for the determination of depression Please see for this method in Appendix.

Observations:—

[*1*] *For l; b; and d*

(i) Distance between the two knife edges (l) =......cm.

(ii) Breadth of the bar (b);

V. C. =

(1) =...cm; (2) =...cm; (3) =......cm

Mean (b) =......cm.

(iii) Thickness of the bar (d)

L. C. of the screw guage =......cm.

(1) =...cm. (2) =...cm. (3) =...cm.

(4) =... cm. (5) =...cm. (6) =...cm.

(7) =... cm. (8) =...cm.

Mean d =...cm.

(2) *Table for the depression (e)*

L. C. of the microscope or spherometer = . cm.

Load put in the pan in k. gm. (b)	Microscope Reading		Mean Microscope Reading $\frac{c+d}{2}$	Depression (e) for 2 k. gm.	Mean depression for 2 k. gm.
	Load increasing (c)	Load decreasing (d)			
0	—	—	— (f)		
½	—	—	— (g)		
1	—	—	— (h)		
1½	—	—	— (i)	(j−f) =	
2	—	—	— (j)	(k−g) =	
2½	—	—	— (k)	(l−h) =	
3	—	—	— (l)	(m−i) =	
3½	—	—	— (m)	(n−j) =	
4	—	—	— (n)		

Calculations — After substituting the values of l, b, d, g, M = 0 gm; and e in the formula $Y = \frac{Mgl^3}{4bd^3e}$, calculate Y.

Result — Y = ... dynes/cm².

Sources of error and precautions — 1. Add or remove the weights tly as possible.

2. Focus the microscope only when the wire or the pin becomes and take the readings on the microscope scale carefully. The ope should not be shifted while taking various readings. It should be moved in the vertical direction. If micrometer screw is used, ll be moved only in one direction to avoid back lash error.

. Through out the experiment the bar should not move on the ges otherwise the mid-point will change.

. As the thickness (d) of the bar occurs as the third power in rula, it should be determined very accurately by taking observ at number of places. A small error in its determination will appreciable error in the determination of Y.

As Hooke's law fails when elongation exceeds 1/10,000 part of the bar, the maximum load should not be beyond the limit.

The knife edge carrying the hanger should be parallel to the edges upon which the scale is placed.

Modifications -1. Draw a graph between load and depression and calculate the value of Y.

2. Prove that the depression produced by loading a bar at its mid-point is inversely proportional to the cube of its thickness.

Criticism and percentage accuracy —

By means of a microscope the depression can be determined accurately up to 0.0002 cm. only. If more accuracy is desired micrometer screw of pitch ½ mm. and L. C.=0.0005 cm. should be employed. As there exists friction between the bar and the knife edges, the result is affected. Though we assume that one end is horizontal, it is not very correct. The beam should be very light and no sagging should take place due to its weight, but this is not always zero. So while increasing the length of the beam this point should always be borne in mind.

Oral Questions—1. Define Y, neuteral axis, and axis of bending, elastic limit, elastic fatigue, breaking stress and strain. 2. How depression is produced? 3. What is a cantilever? 4. In how many ways can you measure the depression produced and which is the best way? 5. Why do you take a bar of longer length and smaller thickness? 6. Why you measure (d) so accurately? 7. What is elastic limit and how will you find this in a particular case? 8. How will you know that screw is just touching the bar? 9. How does Y depend upon temperature? 10. Why the girders are so made that there middle portions are of much smaller width than the upper and the lower faces?

"Always find out

EXPERIMENT No. 2

Experiment:—To determine Young's modulus (Y), modulus of rigidity (η), and Poisson's ratio (σ) of a material of a wire by Searle's apparatus.

Apparatus:—A thin wire of about 25 cm. length and 1 mm. diameter of the material whose Y, η and σ are to be determined, two inertia bars of rectangular or circular cross-section fitted with clamps and screws, a stop watch, a vernier callipers, thread, metre scale, weight box etc.

Description of the apparatus—A B and CD are two identical inertia bars of either circular or rectangular cross-section. The experimental wire whose elastic constants are to be determined is rigidly connected to their centres E and F by clamps. The bars are suspended by two torsion less vertical threads from a rigid support as shown in fig. (1) The bars remain parallel to each other and perpendicular to the axis of the wire.

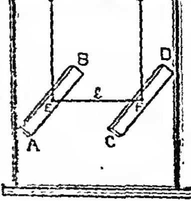

Fig. 1

Theory :—If the ends A and C of the two bars are slightly pulled together through equal distances, the wire is bent in to the form of a

circular arc as shown in fig. 2. If the bars are released they start vibrating in a horizontal plane on account of a couple exerted on them by the wire and vice-versa.

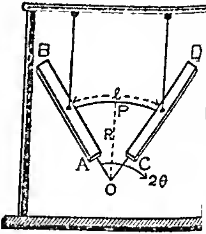

Fig. 2

If M is the bending moment of the wire and the couple exerted by it on each of the bar, Y the Young's modulus of the material of wire, K the geometrical moment of inertia of the wire and R the radius of the arc, we have,

$$M = \frac{YK}{R} \quad \ldots \quad \ldots \quad \ldots \quad (\text{i})$$

and $$R = \frac{l}{2\theta} \quad \ldots \quad \ldots \quad \ldots \quad (\text{ii})$$ where l the length of the wire and θ is the angle through which each bar deflected from its mean position.

From eqns. (i) & (ii) we get,

$$M = \frac{YK\,2\theta}{l}$$

but $K = \frac{\pi r^4}{4}$ (where r is the radius of the wire)

$$\therefore \quad M = \frac{Y\pi r^4}{2l}\,\theta$$

It produces an angular acceleration $\frac{d^2\theta}{dt^2}$ in each bar, and therefore, if I is the moment of inertia of any bar about a vertical axis passing through its centre of gravity, we have,

$$I\,\frac{d^2\theta}{dt^2} = \frac{Y\pi r^4}{2l}\,\theta$$

$$\text{or} \quad \frac{d^2\theta}{dt^2} \propto \theta$$

Hence, as acceleration is $\propto$ to displacement, motion is simple harmonic. If, T_1 is the periodic time of each bar it will be given by

$$T_1 = 2\pi\sqrt{\frac{2Il}{Y\pi r^4}}$$

$$\text{or} \quad Y = \frac{8\pi I l}{T_1^2 r^4} \quad \cdots \quad \cdots \quad \cdots \quad (1)$$

If the bar is of rectangular cross-section,

$$I = M\left[\frac{a^2+b^2}{12}\right] \ldots (2)$$ [Where M is the mass of the bar, a is the length of the bar, b is the breadth of the bar].

If the bar is of circular cross-section.

$$I = M\left[\frac{l^2}{12} + \frac{R^2}{4}\right] \ldots (3)$$ [Where M is the mass of the bar, l is the length of the bar, R is the radius of the bar]

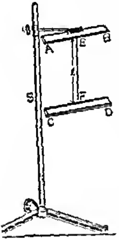

Fig 3

Now the suspension threads are removed and one of the bars is clamped horizontally to a rigid support, so that the other one is suspended vertically below it at the other end of the wire. The suspended bar is if turned in the horizontal plane twists the wire, on releasing, the bar executes simple harmonic tortional vibrations.

If T_2 is the periodic time of these oscillations, we have,

$$T_2 = 2\pi\sqrt{\frac{I}{C}}$$

Where C is the couple per unit twist set up in the wire. It is given by,

$$C = \frac{\eta\pi r^4}{2l}, \text{ Where } \eta \text{ is the modulus of regidity.}$$

$$\therefore \quad \eta = \frac{8\pi I l}{T_2^2 r^4} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

From eqns. 4 and 1 we get,

$$\frac{Y}{\eta} = \frac{T_2^2}{T_1^2}$$

But Poisson's ratio $(\sigma) = \frac{Y}{2\eta} - 1$

$$\therefore \sigma = \frac{T_2^2}{2T_1^2} - 1$$
$$= \frac{T_2^2 - 2T_1^2}{2T_1^2} \quad \text{.................(5)}$$

Method.— To determine Y:

1. Take the experimental wire. Fix its one end to the middle point of one of the bars and the other end to the middle point of another bar. By the help of two vertical threads suspend these bars from a rigid support as shown in fig. 1. The bars must remain horizontal.

2. By the help of a stand put a horizontal pointer in front of one of the bars. To attain better accuracy make a mark on the bar and put the pointer across the mark.

3. Bring slightly the two bars together as shown in fig. 2 and slip a loop of cotton thread over them so that they remain in the deflected position. The curvature of the wire should be very small otherwise the theory will fail.

4. Burn the thread. The bars will begin to oscillate. When the mark crosses the pointer start the stop watch. Determine time for 20, 25, and 30 oscillations. Determine time for the same number of oscillations at least twice. Then determine mean periodic time T_1

5. Determine L. C. of screw gauge, and find out the diameter of the wire at least at 8 different places with its help. Find mean diameter and thence the mean radius r.

6. By the help of a metre scale determine the length of the wire l.

7. Determine the length breadth or thickness of each bar by the help of a scale and a vernier callipers. Weigh them separately in a balance, and calculate the moment of inertia of each bar by either formula (2) or (3). Hence calculate mean moment of inertia I.

8. Knowing T_1, I, r and l calculate the value of Y by eqn. (1).

To determine η:

9. Clamp one of the bars horizontally to the rigid support as shown in fig. 3 so that the other bar remains suspended at the other end of the wire.

10. Put a mark on the suspended bar and put a pointer across the mark.

11. Slightly rotate the bar so that the wire is twisted, and when left, the bar executes angular harmonic vibrations.

12. Start the stop watch when the mark is crossing the pointer, and determine time for 20,25 and 30 oscillations. Determine time for the same number of oscillations at least twice. Then determine mean periodic time T_2.

13. Find r, l, and I as discussed before.

14. Knowing T_2, r, l, and I, calculate the value of η by formula (4).

To determine σ

15. Knowing the values of Y and η determine σ by formula (5).

Observations —

(1) *Length of the wire=......cm..*

(2) *Table for the diameter of the wire*

L. C. = ... cm.

S.N.	Diameter along one direction (x)	Diameter along perpendicular direction (y)	Mean diamter $\left(\frac{x+y}{2}\right)$
1			
:			
4			

Mean diameter =...cm

„ radius (r)=...cm.

(3) *For Moment of inertia of the bar (I)*

(i) Mass of the inertia bar (M) = ... gm.

(ii) Length of „ „ „ (l) = ... cm.

(iii) Breadth of „ „ „ (b) = ... cm.

(iv) Thickness of the „ (if it is circular) (D).= ... cm.

(4) *Table for T_1 and T_2*

Number of oscillations	Time taken 1	2	Mean	T_1	Time taken 1	2	3	Mean	T_2	Mean T_1	Mean T_2
20											
25											
30											

culations :—

First determine the moment of inertia of the bar I by the eqns.,

$$I = M\frac{(a^2+b^2)}{12} \quad [\textit{If rectangular cross section}]$$

$$= M\left(\frac{l^2}{12}+\frac{R^2}{4}\right) \quad [\textit{If circular cross-section}]$$

2. Substitute the values of I, r, l, and T_1 in the equation;

$$Y = \frac{8\pi I l}{T_1^2 r^4} \text{; and determine } Y$$

3. Substitute the values of I, l, T_2 and r in the eqution,

$$\eta = \frac{8\pi I l}{T_2^2 r^4} \text{; and determine } \eta$$

4. Substitute the values of T_1 and T_2 in equation,

$$\sigma = \frac{T_1^2 - 2T_2^2}{2T_2^2} \text{; and determine } \sigma.$$

Result :—

$Y = \ldots$ dynes/cm^2

$\eta = \ldots$ dynes/cm^2

$\sigma = \ldots \ldots$

Precautions and sources of error.—

1. The radius of the wire should be very carefully determined as it occurs in the fourth power.

2. The amplitudes of oscillations while determining T_2 should be very small otherwise the formula will change and the wire will be strained beyond the elastic limit.

3. The bars should not toss up and down, their motion must be in the horizontal plane.

4. As the time periods occur in the second power they should be very carefully determined.

Criticism:—Generally for determining extension for the determination of Y long wire is needed, but in this case, we get good results even with a short length of the wire. This is an extremely fine method for determining σ because it does not entail the determination of Y and η. By simply determining T_1 and T_2 σ can be independently determined. T_1 and T_2 can be determined very accurately whereas there remains always an appreciable error in the determination of the radius of the wire.

Oral questions—

1. Define Y, η, and σ the elastic constants of a material. 2. What are their units and how are they related to each other ? 3. What are the other

methods of determining them, and which are the best 4. What do you understand by elastic limit, stress and strain ? 5. Why the amplitude of the vibration of the rods should be kept small 6. Why the diameter of the wire should be measured so accurately ? 7. What are the forces acting on the rods when they are oscillating ? 8. Why the bars should not move up and down ? 9. Are the moments of inertia of the two bars equal, if not how the error is to be corrected ?

"Before you measure any quantity you must know the accuracy upto which it must be measured and hence choose the measuring instrument accordingly."

EXPERIMENT No. 3

Experiment:—To determine the moment of inertia (I) of a given body by the help of an inertia table using an auxiliarly body of known moment of inertia.

Apparatus:—M. I. Table, an auxiliary body (a rectangle or a right cylinder), the given body whose moment of inertia is to be determined. stop watch, spirit level, a vernier callipers, weight box etc.

Description of the apparatus:—

It conisists of an alluminium circular table T, carrying two vertical rods A and B of equal length. A cross-rod R along with the table is suspended by means of a long wire C, another end of which is fixed to another cross-rod D by means of a chuck. The rod D is fixed to the top of two vertical rods E and F standing on a heavy iron base G. The base rests on three levelling screws. There is a concentric groove cut on the table in which three levelling weights are placed. A mark is also made on the table to indicate its mean position. The table is so adjusted that the axis of suspension passes through its C. G. Some times a plumb line is provided at the bottom of also the table.

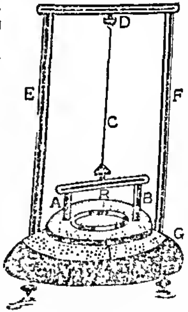

Fig 1

Theory:—When the table is given a slight rotation. It oscillates about the wire as an axis.

If T be the periodic time of tortional vibrations, I the moment of inertia of the table and C the couple per unit radian twist of the wire, then we have.

$$T=2\pi\sqrt{\frac{I}{C}}\dots\dots\dots\dots\dots\dots(1)$$

If T_1 is the time period when a body of known moment of inertia aced on the table,

$$T_1=2\pi\sqrt{\frac{I+I_1}{C}}\quad\text{.........................(ii)}$$

If T_2 is the time period when the given body of unknown moment ia I_2 is placed on the table.

$$T_2=2\pi\sqrt{\frac{I+I_2}{C}}\quad\text{.........................(iii)}$$

From (i), (ii) and (iii) we get,

$$I_2=\frac{T_2^2-T^2}{T_1^2-T^2}\times I_1\quad\text{.........................(iv)}$$

Where $I_1=\frac{M}{12}\left(L^2+B^2\right)$, [If the body of known moment of inertia is a rectangle of sides L and B and mass M.]

$=\frac{Mr^2}{2}$ [If it is right cylinder of mass M and radius r].

$=2/5\ Mr^2$ [If it is a sphere of mass M and radius r]

thod :—1. Level the base with the help of a spirit level evelling screws. The table should not touch the rods E or F.

Put two spirit levels at right angles to each other on the n table and level it. It should become perfectly horizontal. lone by adjusting the position of the levelling weights put in the The levelling can be tested by means of a plumb line also. levelled the axis of the wire will pass through the centre of the table.

See that the reference mark made on the table is in front of the Put a pin fixed in another stand in front of the mark so that e as the reference point indicating mean position.

Gently twist the table through a small angle in the horizontal ave it. It begins to oscillate simple harmonically. when it few oscillations and the mark is to cross the mean position, p watch and find out the time for 20,30, and 40 oscillations. e number of oscillations determine time at least twice. ate the mean periodic time T.

w place the body of known moment of inertia (right cylinder el on the table and again level it. It should be placed so hat the axis of the cylinder or the vertical line passing

through C. G. of the rectangle coincides with the axis of rotation i. e. suspension. Then oscillate the system and similarly determine time for 20,30 and 40 oscillations. Again calculate mean periodic time T_1. T_1 will be greater than T as moment of inertia has increased.

6. Remove this body, and in its place put that body on the table whose moment of inertia is to be determined. Again test for levelling and oscillate the system. Similarly determine time for 20,30 and 40 oscillations. Calculate mean periodic time T_2. T_2 will also be greater than T.

7. Determine the mass (M) of the right cylinder or the rectangle with the help of a balance.

8. Find out the length and breadth of the rectangle or diameter of the cylinder with the help of vernier callipers. These observations should be taken at least in two perpendicular directions.

9. Determine I_1 from step (8) and then calculate I_2.

Observations:—

[1] For moment of inertia of the rectangle or cylinder or sphere:—

(i) Mass of the body (M)=......gm.

(ii) V. C. of the callipers=......cm.

(iii) Diameter of the body =(1)......(2)......(3)......(4)

Mean diamenter (D)=......cm.

Mean radius $(r)=D/_2$=......cm.

Length of the body (1)......; (2)...... (3)......

Mean L=......cm.

Breadth of the body (1)......(2)......(3)......

Mean (B)=......cm.

[B] For determination of periodic times:—

S.N.	No. of oscillations	Time taken with only inertia table in sec.				Time taken with auxiliary body in sec.				Time ta[ken] with the [body] [o]f unknow[n mo]ment of i[nertia] in sec		
		1	2	Mean	T	1	2	Mean	T_1	1	2	Mea[n]
1	20											
2	30											
3	40											

Mean T=............Sec.

T_1=............Sec.

T_2=............Sec.

Calculations:—

1. First of all determine the moment of inertia I_1 of the auxiliary body by the relations.

$$I_1=\frac{M}{12}(L^2+B^2) \text{[If rectangle]}$$

$$=\frac{M}{2}r^2 \qquad \text{[If cylinder]}$$

$$=\frac{2}{5}MR^2 \qquad \text{[If solid sphere]}$$

$\therefore I_1$=........gm × cm²

2. Substituting the values of I_1, T, T_1 and T_2 in equation (iv) determine the value of I_2.

Result :—

I_2=.....gm. × cm².

Precautions and sources of error :—

1. Before starting the experiment all the kinks present in the wire should be completely removed.

2. It is extremely important that the table should alway remain perfectly horizontal, so that it always oscillates about the axis of the wire and its moment of inertia may remain constant. Consequently once the balancing weights are adjusted their position should not in any case be altered.

3. Through out the performance of the experiment the C. G. of the system in all the three cases should lie on the axis of the wire about which the moment of inertia is to be determined.

4. The wire should not be twisted beyond the elastic limit.

5. The table should move in the horizontal plane only without tossing up or down.

6. The body whose moment of inertia is to be calculated must be of uniform density.

Criticism :— For increasing the accuracy in the determination of the periodic times, and decreasing percentage error, the wire should be of greater length and smaller radius. It will increase T, decreasing the percentage error. But smaller is the radius of the wire more will be the kinks present. Therefore, a compromise is made and genrally a wire of 50 cm. length and 0·1 cm. radius is taken. As the load is increased or

decreased, the radius and the length of the wire varies, and therefore, the couple varies. It impaires the accuracy obtained. To obtain better results chronometers should be employed in place of stop-watches and oscillations should be watched through a telescope. The bodies taken of known and unknown moments of inertia should have moment of inertia comparable with that of the table, so that we might get appreciable difference between T, T_1 and T_2 It is assumed that the oscillations are free and that air resistance is negligible. However, if possible, the table part should be enclosed in a box and be prevented from direct drift of wind

Oral questions : —1. Explain moment of inertia of a body giving it physical significance. 2. Give the theorems regarding the moment of inertia. 3. Describe the moment of inertia table and explain why it is so called ? 4. What type of oscillations the table performs ? 5. What is the function of the balancing weights ? 6. Why should not they be disturbed once adjusted ? 7. What is the function of the concentric circles made on the table ? 8. Why do you not take a very long wire of a very thin radius ?

"Always remember it is not the result which you achieve is important; but the method which you employ. So always try to follow only the correct procedure".

EXPERIMENT No. 4

Experiment : To determine the modulus of rigidity (η) of a material in the form of a wire by dynamical method.

Apparatus :— A heavy cylindrical rod or a disc, a long wire of the material whose η is to be determined, an auxiliary body of known moment of inertia, a stop-watch, a screw gauge, a vernier callipers, a spirit level, a weight box, a meter scale etc.

Description of the apparatus:—In this case the experimental wire is taken, and its upper end is rigidly fixed. The lower end supports a heavy cylindrical rod or a disc (the wire is attached to the centre of the cylindrical body).

Theory :- If a rod or a wire is clamped at one end and twisted at the other by applying a couple about its axis and perpendicular to its length, it is said to be under tension. On account of the elasticity of the material, a restoring couple is generated in it. This restoring couple (C) is equal and opposite to the twisting couple. Let the length of the wire be l, its radius r, and coefficent of rigidity (η). If it is twisted through an angle of θ radians at the free end, the twisting couple C is given by the relation,

$$C = \frac{\eta \pi r^4}{2l}\theta \quad \text{......................(i)}$$

$$\text{If } \theta = \text{unity}, C = \frac{\eta \pi r^4}{2l} \quad \text{......................(ii)}$$

When the cylindrical rod is twisted in its own plane and released, it begins to execute simple harmonic tortional vibrations about the wire as an axis. If T_1 is the periodic time, it is given by the relation,

$$T_1 = 2\pi\sqrt{\frac{I_1}{C}} \quad \text{.........(iii)}$$

Where I_1 is the moment of inertia of the cylindrical body, and C is restoring couple per unit radian twist.

If now the auxiliary body is placed on the cylindrical rod, the new periodic time T_2 is given by the relation,

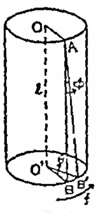

Fig. 1

$$T_2 = 2\pi\sqrt{\frac{I_1 + I_2}{C}} \quad \text{......................(iv)}$$

Where I_t is the moment of inertia of the cylindrical body.

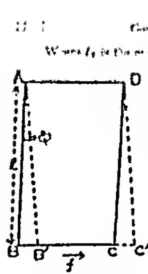

Fig 2

From (ix) & (x) we get,

$$T_2^2 - T_1^2 = 4\pi^2 \frac{I_t}{C} \ldots\ldots\ldots\ldots (x)$$

Substituting the value of C from (ii) in (x) we get

$$T_2^2 - T_1^2 = 4\pi^2 \frac{I_t}{\eta \pi r^4 / 2l}$$

$$= \frac{4\pi^2 . I_t . 2l}{\eta \pi r^4} = \frac{8\pi I_t l}{\eta r^4}$$

$$\text{or } \eta = \frac{8\pi I_t l}{(T_2^2 - T_1^2) r^4} \ldots\ldots\ldots\ldots (xi)$$

Where $I_t = \frac{MR^2}{2}$ ....(vii) [If it is a solid cylindrical body of mass M and radius R].

$= M\left(\frac{R_1^2 + R_2^2}{2}\right)$...(viii) [If it is hollow cylindrical ring of mass M and external and internal radii R_1 and R_2].

Method :— To determine T_1—1. Take a long experimental wire. Clamp its upper end and suspend a heavy cylindrical body from its lower end as shown in fig. 3 The body suspended should remain perfectly horizontal which can be obtained by the help of a sipirit level. The wire should pass through the centre of the body.

2. Mark a vertical line on the body which will serve as reference line. Put a pin in front of the line by a wooden stand.

3. Gently twist the cylindrical body and leave it so that it begins to oscillate simple harmonically in the horizontal plane. It should not toss up and down.

4. After the body has made a few oscillations and the reference mark is crossing the pin start the stop watch. Count the number of oscillations. Find time for 15 oscillations twice or thrice, and then determine time for one oscillation.

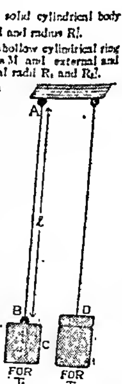

Fig 3.

5. Again find time for 10 oscillations twice or thrice and d mine time for one oscillation. The mean of (4) & (5) mean T_1.

To determine T_2:—

6. Put the auxilary body on the cylindrical disc in such a that again the axis of the wire passes through its centre. Oscillat system in the same way, and determine time for 15 and 10 oscilla twice or thrice. Find mean periodic time. This gives T_2.

7. Determine the length of the wire between its two ends the help of a meter scale. It gives l.

8. Find L. C. of the screw gauge and determine the diamet the wire at least at seven different places. Find mean diameter thence the radius of the wire r.

9. Find the mass of the auxiliary body (ring) by the help balance. Determine its internal and external radii R_1 and R_2 b help of vernier callipers.

Observations:—

[1] *Length of the wire* (l) ... ... cm.

[2] *Table for radius of the wire.*

L. C. = ... cm.

S. N.	Diameter along one direction	Diameter in mutually perpendicular direction	mean diameter (d)
1 ⋮ 7			

$$\text{Mean } r = \frac{d}{2} = \ldots \text{cm.}$$

[3] *For moment of inertia of the auxiliary body:—*

(i) Mass of the ring (M) = ... gm.

(ii) Internal radius (R_1) = ... cm.

(iii) External radius (R_2) = ... cm.

(iv) Radius (R) = ... cm.
(if it is a solid cylinder)

[4] *Observation table for T_1 and T_2.*

S.N.	Number of oscillations	With only cylindrical body				T_1	With the auxiliary ring placed on the body				T_2
		1	2	3	Mean		1	2	3	Mean	
1	15										
2	20										

Mean T_1 = ... Sec,
Mean T_2 = ... Sec.

Calculations :—

1. Calculate the moment of inertia of the ring (I_2) by the formulae (vii) or (viii).

2. Substitute the value of T_1, T_2 l, r, and I_2 in formula (vi) and calculate η by using log tables.

Result :—Modulus of rigidity of the material (η) = dynes/cm².

Precautions and sources of error :—

1. There should not be any kinks in the wire, and it should be quite long and thin.

2. The axis of the wire must always pass through the C. G. of the cylindrical body.

3. The body should simply rotate in the horizontal plane and should not move up and down.

4. The wire should not be twisted beyond the elastic limit otherwise the restoring couple C will not remain $\propto$ to the angle of twist.

5. The time periods T_1 and T_2 should be measured very accurately as they occur in second power.

6. As the radius is to be raised to the fourth power, a very small error in its determination will make an appreciable error in the result. Hence, it should be measured very accurately and at number of different places.

7. The density of the auxiliary body should be uniform through out, otherwise there will be an error in the determination of I_2.

8. It is assumed here that (C) the restoring couple per unit twist remains constant through out the experiment, but it is not rigourously true, because when the load is changed the radius of the wire changes, altering the couple C. It causes some error.

9. The moment of inertia of the auxiliary body is calculated from its geometrical diamentions on the assumption that the density is uniform through out, which is not true in most of the cases. These errors can be removed by employing Maxwell's needles.

Criticism :--See expt. "M. I. Table".

Oral questions :—

1. Explain rigidity, and describe a tortional pendulum. 2. Explain the principle of this experiment. 3. What are the factors upon which the periodic time depends ? 4. If the length is doubled how will the periodic time change ? 5. Will you prefer a thick wire or a thin wire ? 6. Which is the most important quantity to be determined in this experiment ? 7. Does the value of η calculated by statical method agree with the result obtained by this method ? 8. See, experiment on moment of inertia.

EXPERIMENT No 5

Experiment :—To determine the modulus of rigidity (η) of a mater in the form of a rod by statical method (using a horizontal type twistu apparatus).

Apparatus :—Horizontal type apparatus, half kilo-gm. weights (near 12 to 14), a meter scale, a vernier callipers and a screw gauge.

Description of the apparatus:—

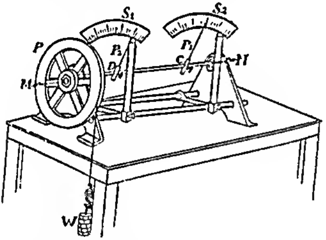

Fig. 1

One end N of the experimental rod is firmly clamped in a block fixed in a frame. The other end is attached to a steel axle of a large pulley P as shown in the figure. A cord is wound round the rim of the pulley. The free end of the cord carries a hanger in which weights can be put. By putting the weights load is applied resulting in a couple on the rod. The rod gets twisted. P_1 and P_2 are two pointers fixed at two adjustable points C and D on the rod. The pointers move over two graduated scales S_1 and S_2 fixed in the frame. The scales are calibrated in degrees. The pointers directly give the twist produced at these two points.

Theory :— If R is the radius of the pulley, M the mass suspended, and g the acceleration due to gravity, the couple acting on the rod is given by,

$$\text{Couple} = MgR \text{ ....} (i)$$

This couple is balanced by the couple due to tortional reaction in the rod, which is given by,

$$\frac{\eta \pi r^4}{2l} (\theta_2 - \theta_1) \text{ ....} (ii)$$

Where r is the radius of the rod, l is the length between C and D where the pointers are situated. θ_2 and θ_1 are the twists produced in radians at the points D and C.

Equating (i) and (ii) we get

$$\frac{\eta \pi r^4}{2l}(\theta_2 - \theta_1) = MgR$$

$$\text{or } \eta = \frac{2MgRl}{\pi r^4 (\theta_2 - \theta_1)}$$

If the angles are measured in degrees the relation will become,

$$\eta = \frac{360\, M g R l}{\pi^2 r^4 (\theta_2 - \theta_1)} \text{ ....} (iii)$$

Note :—In some types of apparatus pointers are not provided, only there is one vernier fixed to the pulley. In such cases l is the length of the rod fixed between the pulley and the block. Instead of $(\theta_2 - \theta_1)$, only one angle of twist θ is to be determined by the vernier fixed on the pulley and the relation becomes,

$$\eta = \frac{360\, M g R l}{\pi^2 r^4 \theta} \text{ ....} (iv)$$

Method :—1. Firmly clamp the end N of the rod in the block attached to the frame. During the experiment this end of the rod should not move in the clamp.

2. Wind a thread round the pulley and suspend a pan at its free end. The thread must remain tangential to the pulley.

3. Fix the two pointers at two points, say C and D along the length of the rod. Adjust the positions of the pointers on the cicular scales such that they read zero. Note down the positions of these two pointers P_1 and P_2 on the cicular scales. This gives zero reading.

4. [illegible]

5. [illegible]

6. [illegible]

7. Find mean readings of θ_1 and θ_2 corresponding to each load.

8. Determine the angles of twist θ_1 and θ_2 for any 2 kilogm. This can be obtained by subtracting 1st reading from the sixth or 3rd from 7th and so on. Determine the mean values of θ_1 and θ_2 for a load of 2 kilogms and hence obtain $(\theta_2-\theta_1)$

9. Measure the length of the rod (l) between the two positions C and D of the pointers with the help of a meter scale.

10. Determine the L. C. of a screw gauge and find out the radius (r) of the rod with its help.

11. With the help of a vernier callipers determine the radius of the pulley R.

12. Knowing M. g. R. l, r, θ_2 and θ_1 determine the value of η.

13. For better accuracy change the length (l) between the two pointers for atleast two to three times, and similarly determine $(\theta_2-\theta_1)$ for a load of 2 kilo gm. From each length determine $\frac{Ml}{\theta_2-\theta_1}$. Find the mean of $\frac{Ml}{\theta_2-\theta_1}$, and substitute this in the formula to get the value of η

Note—As described in theory where there is only one pointer, measure length from the fixed end to the positon of this pointer. This will give l the length of the rod. Determine the angle of twist θ, in the same way. Instead of $\theta_2-\theta_1$ we shall get only θ. Determine θ for a load of 2 k.gm. in a similar way.

Observations:—

(1) For the diameter of the rod:—

L. C. of the screw gauge=.......cm.

S. N.	Diameter in one direction.	Diameter in perpendicular direction.	Mean diameter d
1			
2			
3			
4			

Mean diameter (d)=......cm.

Mean Radius r=d/2=......cm.

(2) *V. C. of the callipers=......cm.*

Length of the rod between the two pointers=..... cm.

or between the fixed end and the pulley (l) = .. cm.

(3) *For the diameter of the pulley*

(i) ....cm., (ii) .... cm.

(iii) .... cm., (iv) ....cm.

Mean diameter (D) =......cm.

" Radius (R) =......cm.

[4] *Observation table for ($\theta_2-\theta_1$) in degrees*

Load in kilogm. placed on the pan	Reading of pointer P_1 in degrees (θ_1) Load, increasing	Load decreasing	Mean	Reading of pointer P_2 in degrees (θ_2) Load Increasing	Load Decreasing	Mean θ	$\theta_2-\theta_1$	θ_5, θ_1 for 2 k. gm.	Mean $\theta_2-\theta_1$ for 2k.gm.
0	—	—	—	—	—	—	—		
½	—	—	—	—	—	—	—		
1	—	—	—	—	—	—	—		
1½	—	—	—	—	—	—	—	(5 1)	
2	—	—	—	—	—	—	—	=	
2½	—	—	—	—	—	—	—	(6·2)	
3	—	—	—	—	—	—	—	=	
3½	—	—	—	—	—	—	—	(7·3)	
4	—	—	—	—	—	—	—	=	
4½	—	—	—	—	—	—	—	(8·7)	
5	—	—	—	—	—	—	—	=	

∴ Mean ($\theta_2-\theta_1$) for 2 k. gm............degrees.

∵ $\frac{M}{\theta_2-\theta_1}=$

Calculations:—

Knowing $(\theta_2-\theta_1)$, l, R, r, g, and M calculate η by the formula,

$$\eta = \frac{360\ Mg\ Rl}{\pi^2 r^4\ (\theta_2-\theta_1)}$$

Result:—

$\eta = ...$dyns/cm^2.

Precautions and Sources of error:—

1. The vertical portion of the string should always be tangential to the pulley.

2. The shear should not exceed the elastic limits otherwise Hooke's law will not hold good.

3. The rod should be firmly clamped in the block fixed in the frame.

4. As the radius of the rod occurs in the fourth power it should be determined very accurately.

5. The weights should be placed and removed gently.

6. If the axle is not mounted exactly at the centre of the pulley, an error may be introduced. This is eliminated by twisting the rod in both the directions of the pulley.

7. If the thread or the string possesses an appreciable diameter, its radius should be added to the radius of the pulley to get the exact value of R.

8. Always there is present a great error in the determination of the angle of twist and radius of the specimen wire. In order to eliminate it a graph should be drawn between load and θ i. e. $(\theta_2-\theta_1)$, and then mean value of $\frac{M}{\theta}$ should be found from the graph. This will very much reduce the percentage error in the determination of θ.

modifications:—1. **To prove that the angle of twist of a given length of a cylindrical rod is directly proportional to the applied couple.**

Hints— 1. If this is to be true M should be directly proportional to θ the angle of twist for the same length of the rod.

2. Therefore, plot a graph between the load M and the twist θ (i. e. $\theta=\theta_2-\theta_1$ in this case) when l is kept constant.

3. It comes out to be a straight line proving the contention stated above. It is as shown in fig (2).

4. The slope of this curve will give mean $\frac{\theta}{M}$ which when substituted in the formula (iii) or (iv) will give η.

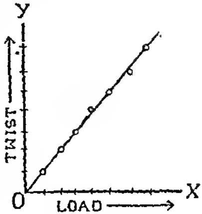

Fig. 2

Modification 2. The angle of twist due to a given couple is proportional to the length of the rod twisted.

Hints :— 1. Take different lengths of the rod, and determine corresponding values of θ and M. Plot graphs for each length. They will be straight lines passing through the origin.

2. Determine $\frac{\theta}{m}$ for each length from the graph.

3. Now plot a new graph between the corresponding values of $\frac{\theta}{m}$ and l. It will come out to be a straight line as shown in fig. 3.

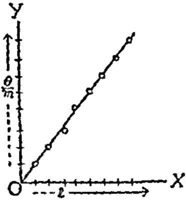

Fig. 3

Criticism :—The graph obtained in this case is almost a straight line. The minor irregularities noticed are (i) due to the non uniformity of the material of the bar. (ii) due to the slight eccentricity of the axis of the rod with respect to the centre of the circular scale.

If longer length of the rod is taken non-uniformity will increase. On the other hand if length employed is smaller the lesser will be the value of twist produced. Therefore a compromise is sought and a

of nearly 1 metre length is taken. Similarly thinner is the rod better the [illegible] but the error due to eccentricity increases. The thicker is the rod lesser is the error due to eccentricity. Hence a compromise is sought.

To eliminate the error due to eccentricity double pointer [illegible] on both the sides of the circular scale may be employed. In this case the circular scale should be a complete circle. The mean of the readings on the two sides will eliminate the error.

As there is only one pulley only a single force is applied to the end of the rod. This produces a side pull on the rod resulting in friction between the rod and the bearings. Hence it greatly impedes the free twisting of the rod.

Oral questions—

1. Explain modulus of rigidity ? 2. How is the rod twisted and the couple applied ? 3. Why one end of the rod is fixed ? 4. Why the thread or the spring should remain tangential to the pulley ? 5. Explain the error due to eccentricity of the axis of rod and show how it is removed ? 6. Why the weights should be placed and removed gently ? 7. What is the maximum load that you can apply ? 8. Why the readings should be taken by winding the string on both the sides of the pulley ? 9. Why the rod in this method should not be very thin ? 10. Why do you not take an extremly long or extremely short length of the wire ?

EXPERIMENT No. 6

Experiment :—To determine η of a rod by statical method (using a vertical type twisting apparatus).

Apparatus :— Vertical type Barton's apparatus, See the previous experiment.

Description of the apparatus :—One end O of the experimental wire OD whose coefficient of rigidity is to be determined, is rigidly clamped to a rigid support as shown in fig. 1. The other end of the wire carries a heavy metallic cylinder C attached to it.

Two cords are wound round the cylinder C moving in the opposite directions passing over the two pulleys KK' The pulleys carry pans in which the weights can be put. The pulleys are identical and of the same weight. A long pointer with two ends is attached to the wire which moves over a circular scale calibrated in degrees. The whole system rests on a heavy frame supported on levelling screws.

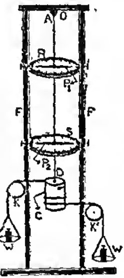

Fig 1

Theory :—When equal weights are placed on the pulleys, they constitute a couple and rotate the cylinder C. Therefore, the wire is twisted. which can be read on the circular scale.

If D is the diameter of the cylinder, M the mass put on the pan. and g the acceleration due to gravity, the moment of the couple acting on the cylinder and the wire is given by.

$$\text{Couple} = M\,g\,D.$$

This is balanced by the couple due to tortional reaction in the wire which is given by.

$$\frac{n\,\pi\,r^4}{2l}\,\theta.$$

Where r is the radius of the wire. l is the length of the wire from the point it is suspended,to the point at which it is clamped to the cylinder, and θ is the angle of twist in radians.

EXPERIMENT No 7

Experiment:—To determine the surface tension of water by Jaeger's method.

Apparatus:—Jaeger's apparatus, a thin glass tube drawn at its one end in the form of a fine capillary, a scale, a thermometer, a microscope etc.

Description of the apparatus:—It consists of a long thin glass tube with its lower end drawn into a fine capillary of about 0·2 to 0·5 mm diameter. The tip of the capillary is perfectly smooth and cut off square. The surface should be perpendicular to the axis of the tube. Even when seen through the microscope the edges of the tube should not indicate any trace of roughness or raggedness. The tube is fixed

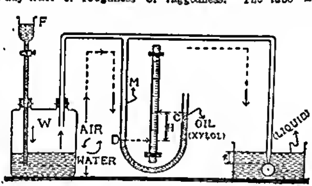

Fig. 1

vertically so that it dips in water (whose surface tension is to be determined) contained in a beaker. About 4 to 5 cm. of its length is kept in side water. This tube is then connected to a manometer M and also to a Woulff's bottle W. The bottle carries a dropping funnel with a stop cock or a burette tube. The funnel and part of the bottle are filled with pure water. Xylol (a liquid hydrocarbon) is used as a liquid in the manometer instead of water, as it has smaller density.

Theory:—When the capillary is dipped in water some water rises in it due to capillary action. The shape of its meniscus is nearly hemispherical. When water is dropped from the funnel in the bottle, the ... its own volume of air. This displaced air is forced into the ... in the tube increases and the surface of the

liquid in the capillary tube is pressed downwards. The level of li goes on sinking lower and lower as the pressure is increased. Finally level reaches the end and a bubble of air is produced into the liquid. As pressure increases the radius of the bubble decreases, until it acquires minimum value. At this stage the bubble acquires more or le hemispherical shape with a radius equal to that of the aperture at the end. it be r. Now the bubble becomes unstable because any further growt the bubble increases its radius decreasing the internal pressure. As external pressure is constant, equilibrium is destroyed and the bu breaks away. Hence just before the bubble gets detached, the pres inside is maximum and is registered by the manometer M.

When the bubble breaks away the pressure inside it is equa $P+H\rho g$, where P is the atmospheric pressure, H is the maxim difference of level of manometer liquid in two limbs, ρ is the densit the manometer liquid and g is the acceleration due to gravity. pressure outside the bubble $= P+hdg$, where h is the depth of th from the surface of water in the beaker and d is the density of water

Thus, the excess pressure inside the bubble

$$= (P+H\rho g)-(P+hdg)$$
$$= g(H\rho - hd).$$

But from the theory of surface tension, the excess pres $= 2T/r$, where T is the surface tension of water.

$$\therefore \quad \frac{2T}{r} = g(H\rho - hd)$$

$$\text{or} \qquad T = \frac{rg}{2}(H\rho - hd) \ldots\ldots\ldots\ldots (1)$$

Knowing all these things T can be determined.

Method:—1. Take the tube clean it and clamp it in a ver position as shown in the figure. The capillary should remain dippi water upto a depth of nearly 3 to 4 cm. A scratch is then mad the capillary and the level of water in the beaker is so adjusted tha scratch coincides with the level.

2. Connect the tube to the manometer M and Woulff's b W with the help of rubber tubing. Make the joints air tight by put wax etc.

3. Fill part of the bottle and the funnel with water and xylol in the manometer limbs.

4. By opening the stop cock of the funnel blow air inside the tube so that the bubble is formed. The flow of water should be so adjusted that bubble is formed after every ten seconds (i. e. at the rate of 6 per minute). When the bubble breaks away, the pressure becomes maximum and then suddenly falls.

5. Note down the maximum pressure when the bubble is just detached with the help of the manometer M. Read the levels of liquid at C and D in the manometer at that time. Difference between C and D will give the maximum difference H. Repeat this process a number of times to get various readings of H. Then determine mean H.

6. Now by pouring or taking out liquid from the beaker change the depth (h) of the tip of the capillary from the surface of the liquid (another scratch is to be made). Repeat the same procedure to determine H. Take at least three different sets with different depths.

7. The levels C and D in the manometer are to be determined with microscope if more accuracy is required. First focus the microscope at C and then at D. The difference will give the value of H.

8. Remove the capillary and clamp it in a horizontal position. Focus a microscope on its orifice. Coincide its crosswires with one of the inner edges and then on the inner edge of the other side. The difference will give the diameter of the tube. Rotate the tube at right angles to the previous position and again determine the diameter. Take a number of such readings, and then determine mean diameter d. Half of it will be the radius (r).

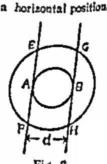

Fig. 2

9. Measure the distance between the tip of the capillary and the corresponding scratches by the help of a scale. It will give the value of h. At least three different sets should be taken after changing h.

10. Calculate surface tension (T) for each set of observations and then determine the mean value of T.

11. With the help of a good thermometer note down the temperature of

Observations :—

[1] Table for the measurement of h and H.

S. N.	Value of h in cm. (a)	Reading of the manometer			Mean H in cm.
		upper level (b)	lower level (c)	H (b-c)	
1					
2					
3					

[2] *Table for the diameter of the capillary*

Least count of the microscope = ..cm.

S N.	Diameter in one direction			Diameter in mutually perpendicular Directions			Mean diameter d
	Reading on one side	Reading on other side	Diameter	Reading on one side	Reading on other side	Diameter	
1							
2							
3							

Mean diameter = ...cm.

Mean radius $(r) = \frac{d}{2} =$ ....cm.

[3] (i) Temperature of water = ...°C.

(ii) density of manometer liquid (ρ) = ...gm/cm.

(iii) density of water $(d) = 1$ (in this case).

Calculations —

Calculate surface tension for each observation by the formula.

$$T = \frac{rg}{2}\,(H\rho - hd).$$

Calculation table

S. No.	h	H	$H\varrho$	hd	$H\varrho-$		g	$T=\frac{rg}{2}(H\varrho-hd)$
1								
2								
3								

Mean T =

Result:—Surface tension of water,

(T) =............dynes per cm. at......°C.

Precautions and sources of error:—1. The capillary tube should be perfectly clean, i. e. it should not have any traces of grease etc., otherwise it will contaminate water altering the surface tension.

2. There should be no leakage in the apparatus otherwise theory will not rigidly apply. Therefore, the apparatus should be in one piece, and rubber joints should be avoided as far as possible.

3. The open end of the manometer should be drawn in the form of a capillary to damp the oscillations of the liquid in it.

4. The bore of the capillary taken should be small i. e. about 2 to 3 mm. If the bore is not smaller, the bubble will not be hemispherical when it is detached from the oriffice of the capillary.

5. As the diameter is quite small, it should be very accurately measured after taking several readings for it.

6. The bubbles should be formed *slowly*, and *singly* i. e. two bubbles should not emerge together. Some time must elapse before the other bubble is formed. If it is not so, the maximum pressure will not remain independent of the rate of bubble formation. These conditions are satisfied if the air space in the bottle is reduced, and flow of water from the funnel is properly regulated.

7. It is very important to note the temperature of water, because surface tension changes with temperature.

Modification.—**To Determine surface tension of water at various temperatures**

Hints.—A heater with a thermostat is placed in the beaker, and T is determined at various temperatures as described above. A graph is then drawn between surface tension and temperature. Surface tension decreases with temperature.

Criticism of the apparatus :—This is quite a good method determining surface tension of liquids. It is specially suitable for study the variation of surface tension with temperature. As the bubble formed within the liquid surface the temperature can be ea controlled. When a graph is drawn between surface tension a temperature, the slope of it can be used to study the molecu aggregation of the liquid (*i. e.* the number of atoms in a molecule).

The danger of contamination of the liquid surface is minim in this case. As the capillary is thin, it can be eas cleaned reducing the possibility of contamination. It increases percentage accuracy.

This method can be employed for determining the surface tens of molten metals.

It is also suitable for studing the variation of surface tens of a solution, with different concentrations of the solute.

As we have to measure the diameter of the capillary only at orifice, the non-uniformity of the bore does not cause any error.

Despite all these advantages discussed above, there is no certai about the radius of the bubble when it breaks away. It may not hemispherical and the same as that of the orifice. The bubble hemispherical only when very narrow capillaries are used. Howev the radius of the bubble has been found to be a function of radius of the aperture. Therefore, for greater accuracy the follow formula is used.

$$T = \frac{rg}{2}\left[H\rho - d\left(h + \frac{2r}{3}\right)\right]$$

Oral Questions :—1. Explain the principle underlying method. 2. Explain whether the excess pressure in side the bub depends upon the depth of the orifice below the surface of the liqui 3. What liquid is used in a manometer and why ? 4. When bubble breaks is its radius exactly equal to the radius of the orifi If not, what corrections should be made ? 5. Why maximum press is noted ? 6. What should be the convenient rate of formation of bubbles ? 7. Is this method superior to that of capillary rise, if what are the merits ? 8. How does surface tension change w temperature ?

EXPERIMENT No. 8

Experiment :—To determine the surface tension of water t capillary tube.

Apparatus :—Glass tube for drawing capillary tubes, or re made capillary tubes of uniform bore, a glass plate, a pin, wax, microscope, beaker, stand etc.

Theory:—If a capillary tube of small radius is dipped in liquid, liquid rises in it on account of surface tension. The meniscus the liquid is concave upwards as at P. The meniscus is in contact with a tube of length $2\pi r$, if r is the radius of the tube at P. If T is the surface tension of the liquid, the force exerted by the meniscus on the tube is equal to $2\pi r$T in the direction of the arrow, where θ is the angle of contact. As action is equal to reaction the tube will exert force on the liquid, and the liquid will rise up. The horizontal components of this force will cancel out and the vertical components will be equal to $2\pi r$ T $\cos\theta$.

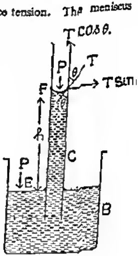

Fig. 1

If h is the height to which the water rises, the volume of water in the tube up to the meniscus

$$=\pi r^2 h+\text{ volume of meniscus}=\pi r^2 h+\pi r^3-\frac{2}{3}\pi r^3$$

$$=\pi r^2 h+\frac{\pi r^3}{3}=\pi r^2\left(h+\frac{r}{3}\right)$$

Weight of this liquid column will be,

$$\pi r^2\left(h+\frac{r}{3}\right)dg, \text{ wh}$$

d is the density of liquid (*for water* d $=1$ *gm/c.c.*)

The water will rise till the upward force due to tension is balanc

... the downward force of gravity.

$$\therefore 2\pi r T \cos\theta = \pi r^2 \left(h + \frac{r}{3}\right)^{}... \quad ...(i)$$

$$\text{or } T = \frac{r\left(h + \frac{r}{3}\right)g}{2\cos\theta}$$

For water $\theta = 0$ and $\cos\theta = 1$

$$\therefore \ T = \frac{r\left(h + \frac{r}{3}\right)g}{2} \ldots\ldots(ii)$$

$$= \frac{rhg}{2} \ldots\ldots\ldots\ldots(iii)$$ where $\frac{r^2}{6}$ may be neglected as r is extremely small.

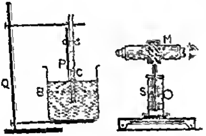

Fig. 2

Method-1. Take two or three glass tubes. Clean them first by o soda and then by sulphuric acid and nitric acid. Rinse

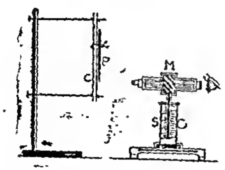

Fig. 3

with tap water and dry. Heat one of them in a Bunsen flame,

and draw three or four capillary tubes of uniform bore (r=from 0·1 to ·02 mm.). If prepared capillary tubes are provided, wash them as explained above.

To determine h:—2. *Take a thin clean glas plate. Fix one of* the capillary tubes along the length of the plate by wax or by rubber bends. Also attach a pin P at the *bottom of the plate* so that it remains parallel to the capillary tube as shown in the figure.

3. *By the help of a stand*, put the plate just above a beaker filled with uncontaminated tap water. in such a way that the capillary tube *dips in water, and the pin head is just above the level of water* in the beaker. Care should be taken to see that the capillary tube is *perfectly vertical. The pin head will give the level of water* in the beaker. Due to surface tension water will rise up in the tube.

4. *Take a microscope and determine its L. C. Put it in such way that its scale is vertical while its tube is horizontal. Focus* its eye piece on the crosswires. Now put its objective in *front* of the pin head, and see the inverted image of the pin head. Adjust it in such a way that its horizontal crosswire just touches the pin head. Take the reading on the microscope scale. It corresponds to the level of water in the beaker.

5. Raise the microscope tube along the scale without bodily displacing it and now focus it on the meniscus of water in the capillary tube. An inverted image of the meniscus will be seen. Adjust it in such a way that the horizontal cross-wire is tangential to the lowest portion of the meniscus. Take the reading on the microscope scale.

6. *Difference between the two readings (4) and (5) will give the* height through which water has risen in the tube. *Repeat this process* at least twice and then determine mean height *h*.

7. *If the capillary drawn is of such a small bore that the* capillary rise is greater than 5 cms. it is not necessary to determine it with the help of a microscope. Instead, the capillary tube may be fixed against a glass scale preferably graduated in to half millimeters. The capillary rise can be directly measured on the scale.

To determine r:—8. Make a mark at the meniscus of water in the tube. Remove the capillary tube. By means of a sharp file cut the tube at the mark. Hold the broken tube horizontal in a clamp stand [illegible] a travelling microscope in front of it. The [illegible] which has been [illegible] by the file should face the travelling microscope [illegible]

of the tube is to be determined at the place of the water menisc
See fig. 3.

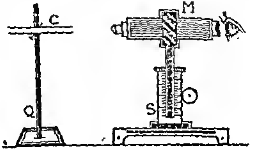

Fig. 3

9. To find out the internal diameter of the capillary tube, ad the microscope so that its vertical crosswire is tangential to the hand side of the inner circumference of the capillary tube. T the reading of the position of the microscope tube, on the scale which it is travelling. Move the tube horizontally so that now the ve cal crosswire is tangenial to the right hand side of the inner circur rence Again take reading on the microscope scale. The d rence, between these two readings will give the internal diameter of tube. Turn the tube in its position by a right angle, and again de mine the diameter similarly. The mean of these two readings will the internal diameter. For accuracy one or two more sets of observat may be taken. Calculate radius from this reading.

10. Replace this capillary tube by another one of a diffe bore. Similarly determine the height of water risen, and the radiu the tube. The process should be repeated at least with three or capillary tubes of different bores.

11. Knowing h and r for every tube, find the product h r each observation, and determine mean of h r. Then with the form (iii) calculate surface tension T.

12. Determine the temperature of water in the beaker wit thermometer reading up to $\frac{1}{2}$°c and note it. (It is because su tension varies with temperature).

Observations :—

Temperature of water = ...°c.

[1] *Table for capillary rise (h)*

No. of tube	Reading of Microscope At Level of water (a)	At the upper meniscus (b)	Difference (b−a) h
1			
2			
3			

[2] *Table for radius of the capillary.*

S.N.	Diameter in one direction Reading on L.H.S.	Reading on R.H.S.	Diameter	Diameter in mutually perpendicular direction Reading on L.H.S.	Reading on R.H.S.	Diameter	Mean Diameter
1							
2							

Mean diameter d = ... cm.

" Radius $r=d/2$ = ... cm.

Calculations :—

S.N.	r in cm.	h in cm.	rh	Mean rh	$T=\frac{hrg}{2}$
1					
2					
3					
4					

esult :—T = ... dyns per cm. at °C.

Precautions & Sources of error :—

1. The capillary tube should be kept perfectly vertical, other-se there will be an error in the measurement of h.

2. The water, beaker, and the capillary tube must be clean. ey should not be contaminated with grease or oil. If they are ntaminated, surface tension will change and the liquid will not rise the tube to the proper height. As this mistake is mostly committed, ccuracy is the aim, this point should be clearly born in mind while ng the experiment. Do not use distilled water as it is likely to tain grease. If the water is not contaminated, water will drop in beaker when the tube is removed.

3. The top of the tube should be kept open. It should not get ked by wax etc.

4. Mind it that the radius of the tube is to be determined at the place where the level of water stood in the tube. That is why it is broken from that place. The bore should be uniform, otherwise if the radius is determined some what above or below that point, it will cause an error in the determination of r. The uniformity of the bore can be ascertained by introducing a pellet of mercury in side the tube. Measure the length of the thread at diffrent places. If the length comes out to be the same, the bore is uniform.

5. Determine the diameter of the tube at least in two perpendicular directions. While determining it try to avoid the back lash error.

6. Do not forget to note down the temperature of water other wise the result will be meaning less.

7. The bore of the capillary should be fine otherwise h will be smaller.

8. To make the angle of contact zero, it is better to wet the the tube a little above also.

Criticism :—This method gives fairly good results. It is only applicable in the cases where the angle of contact is zero. Otherwise, the value of T will be unreliable because the angle of contact is always uncertain. If the liquid is contaminated the angle of contact will change altering the value of surface tension.

If the capillary taken is of uniform bore the radius can be accurately determined by introducing a pallet of mercury in side the tube, and measuring its length and mass. If l is the length, m is the mass and r is the internal diameter of the tube, the volume of mercury thread will be $=\pi r^2 l$, if d is its density, $m=\pi r^2 l d$.

$$\text{or } r=\sqrt{\frac{m}{\pi l d}}$$

But it is extremely difficult to obtain a tube of perfectly uniform bore. Thus, the radius of the tube at the meniscus cannot be determined with a high degree of accuracy. Furthermore, often the contamination of water takes place and the students fail to obtain correct values.

If it is possible to cut the bore at the end up to which water rises, then uniformity of the tube is not important. As such, students

As capillary rise is very large, it is not necessary to measure it correctly up to third place of decimal with a microscope, though usually it is measured with a microscope.

Contamination of water surface with any metallic contact should be avoided. Instead of a metallic pin it is better we use a glass style.

Oral Questions :—

What do you understand by surface tension, and how does it arise ? Give its units. 2. How does surface tension differ from elastic forces ? what is the difference between a stretched rubber sheet and a liquid surface ? 3. Why the liquid rises in a tube. 4. Define the angle of contact ? When is the meniscus concave or convex and why ? What is the value of angle of contact in case of (a) water and glass (b) mercury and glass. 5. Why the capillary tubes of fine bores are taken ? What is the defference in pressure just on the two sides of the meniscus ? 7. Wi l height *h* change if more of the tube is pushed in the liquid ? How does T varies with temperature ? 9. Why are globules of mercury spherical ? 10. Why is it difficult to introduce mercury in a fine thermometrical capillary tube ? 11. Why does oil spread over the surface of a liquid ? 12. Do you know any other methods of determing surface tension ? Which is the best ?

EXPERIMENT No. 9

Experiment:—To determine the coefficient of viscosity (η) of r. determining the rate of flow through a capillary tube by Poiseui method, at room temperature.

Apparatus:—A capillary tube, viscosity apparatus, two constant baths, a graduated cylinder, stop-watch, a thermometer, weight tc.

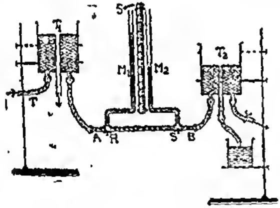

Fig. 1

lescription of the apparatus:—T_1 is a costant level bath carried and. It can be raised up or lowered down. Its inlet tube is ed to the tap, while the central constant level tube is connected sink. The out let tube is connected to a long capillary tube AB lore through a glass T with the help of rubber tubing. The d B of the capillary tube is also connected through a T piece to constant level bath T_2 as shown in the figure. The out let T_2 is closed by wax, and water is collected in a beaker from the onstant level tube. M_1 and M_2 are the two limbs of a mano- The limbs of the manometer are arranged over two fine holes over the capillary tube through T pieces. A scale S is provi- ween the two limbs of the manometer to read the levels of water

in them. The difference in the levels of water in the two limbs directly gives the difference of pressure between the two ends of the capillary tube AB. The tube AB remains perfectly horizontal.

At some places a simpler apparatus as shown in fig. 2 is used.

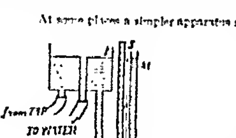

Fig. 2

In this case L is a constant level bath connected to one end of the capillary tube A through a T piece. At A a tube M is connected which serves the purpose of a manometer giving the level of water of the constant level bath. A scale is attached by the side of M to read the height of water column in it. The zero of the scale coincides with the axis of the tube AB. The end B is open, and below it is placed a beaker, in which water can be collected.

Theory:—When a liquid is allowed to flow through a narrow tube it opposes the relative motion between its different layers on account of viscosity. Therefore, to maintain steady flow of the liquid some pressure is needed. If V is the volume of water in c. c. flowing per sec., then by Poiseuille's equation it is given by,

$$V = \frac{P\pi a^4}{8\eta l} \quad \text{.................(i)}$$

Where P is the pressure difference between the ends of the capillary tube AB in dynes, a the radius of the tube in cm., l the length of the capillary tube in cm., and η the coefficient of viscosity of water.

$$\therefore\ \eta = \frac{P\pi a^4}{8Vl} \quad \text{.................(ii)}$$

If h is the difference between the levels of water in the two manometric limbs (or the difference between the level of water in the tank denoted by M and the horizontal plane carrying the axis of the tube), d the density of water, and g the acceleration due to gravity, then we have,

$$P = hdg = hg \text{ [as } d \text{ for water} = 1]$$

$$\therefore \quad \eta = \frac{hg\pi a^4}{8Vl} \quad \text{......................(iii)}$$

$$= \frac{\pi a^4 g}{8l} \cdot \frac{h}{V} \quad \text{..................(iv)}$$

Note:—poiseuille's formula holds good only when the velocity of flow of the liquid is below the critical velocity. The critical velocity depends upon the bore of the tube and viscosity of the liquid.

Method:—1. Take a thick walled capillary tube of nearly 0·5 mm. in diameter and 40 cm. in length. Clean it by HNO_3, H_2SO_4 and Na OH. Rinse it then by tap water. Place it horizontally on the table Connect one of its ends A to the constant level bath T_1 through a T piece with rubber tubing The other end B is also connected to the second constant level bath T_2. Close the out let tube of the constant level bath T_2. Beaker is placed below the constant level tube of T_2 to collect water.

2. Through T pieces arrange the two limbs of the manometer over the holes at R and S as shown in the figure. The two limbs should remain perfectly vertical. The holes R and S where the manometric limbs are connected to the tube AB should be at least 10 cm. away from the capillary tube. In the apparatus of the second type connect the end A to the manometer M.

3. Open the tap so that water comes in T_1. By raising or lowering it and also adjusting T_2, fix the baths in such positions that the water begins to come out of the constant level tube of T_2 in a steady trickle. The discharge of water should not be too large. In second type of apparatus water comes out at the end B. Generally 10 to 30 drops per minute are sufficient.

4. Take a completely dried and cleaned graduated cylinder and put it below the constant level tube of T_2 or the end B as the case may be. The water will begin to collect in it. As soon as you start collecting water start the stop watch.

5. When sufficient water has been collected say about 100 c. c. stop the stop-watch and remove the cylinder. Determine the volume of water collected from the graduated cylinder and time *t* from the stop watch. From this observation calculate the volume V of water flowing per second.

6. Read the level of water in the two limbs M_1 and M_2 and then determine the difference of level between the two limbs. It will give *h*. In another type determine *h* from the manometer M.

7. Now change the positions of the two baths by lowering or raising them along the stands. Consequently the pressure will change changing, the rate of flow of water. As described above determine the correspon ding values for V and h. In this way change the pressure at least for three to four times. Each time determine the value of V and h.

8. From each observation, determine the value $\frac{h}{V}$ and then calculate mean $\frac{h}{V}$.

To determine radius :—

9. Remove the capillary tube and put it horizontally on a clamp stand. Take a travelling microscope and determine its L. C. Probably it should be 0'001 cm. Focus it on one of the ends of the tube and determine its internal diameter in this position as described in the expt. on surface tension. Move the tube by a right angle and again determine the internal diameter. Now repeat the same procedure putting another end in front of the microscope. The mean of three or four readings will give the diameter of the tube from which the radius of the tube a is calculated,

Note:—A better method of determining radius is as follows:—Introduce a pellet of mercury in the capillary tube. Find its length at a few places in the tube and then determine the mean length. Let it be x. Now by taking the mercury in a previously weighed watch glass find the mass (m) of mercury pellet of length x. If a is the radius of the tube, volume of this much of mercury will be $=\pi a^2 x$. If d is the density of mercury.

$$m = \pi a^2 x . d$$

$$\text{or } a = \sqrt{\frac{m}{\pi x d}}$$

10. Find the length of the capillary tube with the help of meter scale.

11. Find the temperature of water in the level bath by the help of thermometer.

12. Calculate η, the coefficient of viscosity by the formula. (iv)

Observations—(1) Temperature of water =......°C.

(2) Length of the capillary tube =.........cm.

[1] *Observation table for h and V:—*

S.N.	Reading of the level of water in M_1 in cm (h_1)	Reading of the level of water in M_2 in cm. h_2	$h = h_1 - h_2$	volume of water flowing in c. c. V'	Time in Sec.	Volume V for one sec.	$\frac{h}{V}$	Me h
1								
2								
3								
4								

[2] *Observation table for the internal diameter of the tube:—*

L. C. of the microscope = ...cm.

S.N.	One end of the tube						Another end of the tube						Mea Diame (d)
	Diameter in one direction			Diameter in Perpendicular direction			Diameter in one direction			Diameter in Perpendicular Direction			
	Reading L.H.S.	Reading R.H.S.	Diameter	Reading L.H.S.	Reading R.H.S.	Diameter	Reading L.H.S.	Reading R.H.S.	Diameter	Reading L.H.S.	Reading R.H.S.	Diameter	
1													
2													

Mean diameter d = ... cm.

Mean radius $a = d/2$ = ... cm

or

(i) Length of the mercury pallet at various places =

(1) ... cm (2) ... cm. (3) ... cm.

Mean = ... cm.

(ii) Mass of the watch glass = ... gm.

(iii) Mass of watch glass + mercury = ... gm.

(iv) Mass of mercury $(m) = (3-2)$ = ... gm.

(v) Density of mercury (d) = 13.6 gm/cc.

$$a = \sqrt{\frac{m}{\pi l d}}$$

Calculations:— Mean a = ... cm.

$$\frac{h}{V} = ...$$

EXPERIMENT No. 10

Experiment:—To determine the mechanical equivalent of he by mechanical method (Searle's friction cone method).

Apparatus.—Searle's apparatus, a weight box, a thermomet balance etc.

Description of the apparatus:—A and B are two trunc cones of gun metal, fitting closely in to one another. The inner cone remains projecting over the outer one. The outer cone is fixed to an ebonite disc by pins. The ebonite disc is fixed to a vertical spindle S which can be driven by hand or by electric motor, C is a counter which gives the number of revolutions which the spindle makes i. e, it gives the number of revolutions made by the outer cone.

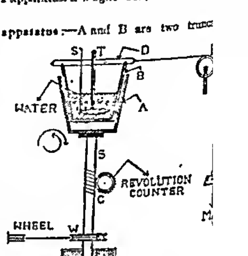

Fig. 1

The inner cone B is rigidly fixed to a wooden disc D. A groove cut in the edge of the wooden disc around which passes a string. Th string passes over a pulley P and carries a mass M at the other end. is a thermometer placed in the inner cone, which is filled with water.

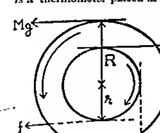

Fig. 2

Theory:—When the out cone is rotated the inner one al tries to rotate with it on accou of friction between them. But th string is so wound that the weig tries to move the cone in the oppo site direction. The weight is s adjusted that when the outer con is moving the inner remain stationary. In equilibrium, th moment due to the force Mg abou

the axis of the spindle must be equal to the moment due to the frictional force. Hence we have,

$$MgR = Fr \text{..........................(i)}$$

Where M is the mass suspended, g is the acceleration due to gravity, R is the radius of the disc, F is the mean value of the frictional force between the two cones and r is the mean radius of the surface of contact of the two cones.

If the outer cone makes n revolutions, the work done W by the force of friction in given by,

$$W = 2\pi n r F \text{..................(ii)}$$

From (i) and (ii) we get,

$$W = 2\pi n Mg R \text{...............(iii)}$$

When so much amount of work is done, it will produce heat which will increase the temperature of the cones and water. The heat produced is given by,

$$H = (m_1 S + m_2)\ (t - t_1) \text{.....(iv)}$$

Where m_1 is the mass of the two cones including stirrer,

S is the sp. heat of the material of the cones,

t is the final corrected temperature of water and cones,

t_1 is the initial temperature of water and cones,

m_2 is the mass of water in the inner cone.

But according to joule's law

$J = \frac{W}{H}$, therefore, from (iii) and (iv) we get,

$$J = \frac{2\pi n M g R}{(m_1 S + m_2)\ (t - t_1)} \text{ ... ... (v)}$$

Method—1. Take the two cones and clean them. Place one n to another and see whether the outer one can rotate about the inner one or not. If the friction is too large reduce it by lubricating the surfaces of the cones by oil. See that very little oil is used.

2. Determine the mass of the two cones including the stirrer by balance. Let it be m_1 gm. Remember that usually the cones are very heavy and so you need not use a sensitive balance.

3. Fill the inner cone up to nearly two thirds with water and again weigh the two cones. The difference between this reading and the former one gives the mass of water filled in the cone. Let it be m_2 gm.

4. Fix the outer cone on the ebonite disc, and place the wooden disc above the inner cone. Fix one end of the string on the groove of the disc and suspend a pan carrying a mass M by its another end. It is very important to see that the string while passing over the pulley remains perfectly tangential to the disc D. Now rotate the spindle S by hand or by electrically driven motor.

5. Put the thermometer T in the inner cone passing through the disc through a cork.

6. Adjust by trial and error the mass in the pan in such a way that while the outer cone is moving the inner one remains stationary. (Though students encounter great difficulty in doing this in the beginning, after some practice it will become very easy). When this adjustment has been done note the initial temperature of water and the cones by the thermometer T. Also note the reading of the counter.

7 Now start the stop watch and go on moving the outer cone by driving the wheel. It is again very important that the wheel should be driven at a constant speed, otherwise the inner cone will not remain stationary. Stir the water constantly so that the temperature remains uniform.

8. When the temperature of water in the cone rises by about 5° to 10°C, stop, rotating the spindle and the watch. Read the final temperature of water (t_2) by the thermometer. Determine the time T by the stop watch for which the wheel has been rotated.

Again read the position of the counter and determine the number of rotations (n) performed by the outer cone.

To determine Radiation correction:—9. To obtain the radiation correction, find the fall in temperature for the same time for which the experiment was done. Let it bet t_3 °C, then the radiation correction will be $\frac{t_3}{2}$ °C. Add this value to t_2 to get the final corrected temperature.

10. To determine the circumference of the disc $2\pi R$, take a thread and pass it round the disc completely, and then measure it on a meter scale. To get more accurate value, two or three turns of the thread are taken, and the length of the string is determined for these

turns. Dividing it by the number of turns, the length for one turn ca obtained.

11. Calculate the value of J by substituting the correspon values in formula (v).

12. If there is time left, vary the speed of rotation, and the M suspended by the thread. Repeat the procedure in the way, to get the new values, and calculate for J.

13. If you have taken few sets of observations, determine each set, and then calculate the mean value of J.

Observations:—

1. Mass of the two cones with stirrer (m_1) = ...gm.
2. Mass of the two cones + water in the inner cone (m_2) = ...gm.
3. Initial temperature of water (t_1) = ...°C.
4. Final " of " (t_2) = ...°C.
5. Initial reading of the counter (c_1) = ...
6. Final " " c_2 = ...
7. Mass of the load suspended from the string (M) = ...gm.
8. Fall in temperature of water after cooling through the same time for which the expt. is done......... = ...t_3°C.
9. Circumference of the disc D $(2\pi R)$ = ...cm.
10. Sp. heat S of the material of cones = ...

Calculations:—

1. Mass of water (m_3) = ob. 2 − ob. 1 = ...gm.
2. Rise in temp. (t_2-t_1) = " 4 − " 3 = ...°C.
3. No. of rotations made by the cone = $(n) = C_2 - C_1$ = ob. 6 − 5 = ...
4. Final corrected temp. $t = \left(t_2 + \frac{t_3}{2}\right)$°C
5. Radius of the disc R = ... cm.

Substituting the proper values in the formula.

$$J = \frac{2\pi n M g R}{(m_1 S + m_3)(t_2 + \frac{t_3}{2} - t_1)}$$, calculate J.

Result: —The mechanical equivalent of heat =......ergs/calorie.

Precautions and sources of error:—

1. The string carrying the mass should remain tangential to the disc.

2. The disc must remain stationary i. e. the mass suspended must remain at the same level. This can be achieved by adjusting the rotation of the wheel. As the temperature rises, to keep the disc stationary the wheel will have to be rotated with more speed.

3. Before starting expt. the cones should be properly lubricated, otherwise friction will be extremely large, and it will be very difficult to perform the experiment.

4. The pulley P should have minimum friction, otherwise it will tend to change the value of Mg in the formula.

5. The water should be constantly stirred.

6. The radiation correction should always be applied.

7. The water in the inner cone should not be so much that it may spill out.

8. A thermometer reading upto $\frac{1}{2}$°C or $\frac{1}{5}$ °C should be used to note the temperatures.

Criticism —The value of J found by this method is not very accurate due to the following reasons.

(i) The rise of temperature is very small, and therefore it cannot be determined very accurately.

(ii) The temperatures are determined by mercury thermometers and not by standard thermometers.

(iii) Though the radiation correction is applied, radiation losses are still there, and the amount of heat calculated is less than the heat generated. Therefore, the value of J obtained by this method is slightly higher.

(iv) The assumption that the total work done which is converted into heat is wholly taken up by the cones is wrong. Hence the result is not very accurate.

Oral questions —

1. What is Joule's law ? 2. Define J and give its units ? 3. How is heat generated in this experiment ? 4. Is this process reversible or irreversible ? 5. Why is it necessary to adjust the speed of rotation so that the suspended weight remains at the same level ? Is it necessary to rotate the spindle at a constant speed ? 6. If you increase the weight suspended, why the heat generated increases ? 7. Why the string should remain tangential to the disc ? 8. Which of the two cones rotate ? 9. What is radiation correction and how is it applied ? 10. Why the results obtained by this method are high ?

EXPERIMENT No. 11

Experiment :—To determine the thermal conductivity of copper in the form of cylindrical rod by Searle's apparatus.

Apparatus :—Searle's apparatus, two thermometers reading up to [illegible]°C, and two thermometers reading up to $\frac{1}{5}$°C, a constant level bath, a boiler with a *burner to prepare steam*, *measuring* flask, vernier callipers, meter scale, weight box, rubber tube etc.

Description of the apparatus :—AB is a thick cylindrical bar of copper. The end A is placed in the steam chest C, in which steam

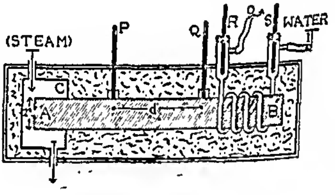

Fig. 1

can be admitted from the boiler. The steam after heating the end A passes out from the other out let. A copper spiral tube is welded around the other end B of the bar as shown in the figure. The ends of the spiral tube carries cups in which thermometers can be placed. Cold water is circulated in the spiral tube. Cold water is allowed to enter the spiral tube from a constant level bath (not shown) to ensure steady flow. After circulating, the water comes out from the other end after taking heat from the bar, which can be collected in a cylinder. The two thermometers S and R give respectively the temperatures of in flowing and out flowing water. Two holes are drilled at a convenient distance along the bar, and two thermometers P and Q are placed in them. To secure better contact, mercury is placed in

hese holes The whole apparatus is surrounded by felt or cotton wool o prevent the heat from going out, and is packed in a wooden case.

Theory :—In the steady state the heat flowing through the bar er sec. is absorbed by the circulating water at the other end. Let be the mass of water flowing in t sec., and θ_4 and θ_3 be the mperatures of in flowing and out flowing water; then heat taken up water per sec. will be.

$$= \frac{M}{t}\ (\theta_3 - \theta_4) \quad \text{.........} \ (\text{i})$$

But the heat Q flowing per sec. through the bar is given by,

$$Q = K\,A\,\frac{\theta_1 - \theta_2}{d} \quad \text{.........} \ (\text{ii})$$

Where K is the coefficient of thermal conductivity of the material of the bar.

A is the area of cross-section of the bar,

θ_1 and θ_2 are the steady temperatures recorded by P and Q and,

d is the distance between these two thermometers.

Equating (i) and (ii) we get,

$$K\,A\,\frac{\theta_1 - \theta_2}{d} = \frac{M}{t}(\theta_3 - \theta_4)$$

$$\text{or } K = \frac{M(\theta_3 - \theta_4)d}{t\,A\,(\theta_1 - \theta_2)} \quad \dots \dots \dots \ (\text{iii})$$

If the radius of the bar $= r$; $A = \pi r^2$

$$\text{or } K = \frac{M(\theta_3 - \theta_4)\,d}{t\pi r^2\,(\theta_1 - \theta_2)} \quad \dots \dots \dots \ (\text{iv})$$

Method :—1. By means of rubber tube connect the steam chest oiler. Pass steam through it so that the end A is heated and the asses through the bar. Put two thermometers P and Q in the

2. Connect the farther end of the spiral tube to a constant level and allow the water to circulate in the spiral. For this onnections with the bath are to be made as explained . on viscosity. The water should come out only in the f a trickle otherwise the temperature difference between the ng and out flowing water will be very small. Insert two meters R and S in the cups at the two ends of the spiral. These meters should be able to read up to 1/5°C. The flow should be nal such that the difference of temperature between the two neters be more than 5°C.

3. Now wait till the bar attains steady state. It should be clearly noted that the rate of flow of water in the spiral must remain constant throughout. When steady state is reached, the temperatures indicated by the four thermometers will attain a steady value. (Note it that in the steady state the four thermometers do not show the same temperatures). Whether the bar has attained the steady state or not can be determined by noting the temperatures in the four thermometers after every five minutes. If there is no change in the respective values of temperatures denoted by them, the bar is said to have attained the steady state. It takes about 30 to 40 minutes to obtain this condition.

4. When the bar has attained the steady state, read the four thermometers. Let the temperatures denoted by them be θ_1, θ_2, θ_3 and θ_4, respectively.

5. To determine the mass of water flowing per sec. in the spiral tube, take a clean and perfectly dry measuring cylinder. Start the stop watch and collect water in this cylinder for a certain interval of time say, t seconds. Determine the volume of water from the cylinder. As the density of water is unity the volume will be equal to the mass. Knowing mass (M) discharged in time t, determine the rate of flow, i. e. mass flowing per second. The mass collected can also be determined by taking a weighed beaker, and then collecting water in it. Again weigh the beaker after the water has been collected. The difference between the two masses will be the mass of water which has been collected in t seconds.

6. Now repeat the whole process again after changing the rate of flow of water. It can be done by altering the position of the constant level bath. Once the rate of flow is varied, you have again to wait till the steady state is reached. Again determine θ_1, θ_2, θ_3, θ_4 and M in the same way. It takes nearly half an hour to reach the steady state. Hence it is advisable not to change the rate of flow, but for the same rate of flow, collect water for different timings.

7. Measure the distance d between the two hole with the help of vernier callipers.

8. Measure the diameter of the bar also with the help of vernier callipers. Determine the diameter at three or four different places on the bar. And then calculate mean diameter.

9. Calculate the value of K by each set of observation and then determine the mean value of K.

Observations:—

Length of the bar between the holes =.........cm.

[1] *Determination of the radius of the bar*—

L. C. of vernier callipers =............cm.

S. No.	Diameter in any position	Diameter in perpendicular position	Diameter	Mean Diameter
1	—	—	—	
2	—	—	—	

$r = \frac{\text{Diameter}}{2} =$.........cm.

[2] *To know whether steady state is reached or not* :—

S. No.	Time	θ_1	θ_2	θ_3	θ_4
	5 min.	—	—	—	—
	10 "	—	—	—	—
	15 "	—	—	—	—
	20 "	—	—	—	—
	25 "	—	—	—	—

Conclusion :—Temperatures are steady.

[3] *Observation table for* θ_1, θ_2, θ_3, θ_4, M *and* t—

S.No.	θ_1 °C	θ_2 °C	θ_3 °C	θ_4 °C	Mass of water collected (M) in gm.	Time taken t in sec.	Rate of flow $m = \frac{M}{t}$	Mean $\frac{M}{t}$
1								
2								
3								

Calculations:—From each set of observation calculate K and then determine mean value of K.

Result:—The coefficient of thermal conductivity of copper =......calories/sec/sq. cm./unit temp. gradient.

Precautions and sources of error:—1. The bar should be covered with cotton wool or felt otherwise radiation losses will become appreciable.

2. While taking one set, the rate of flow of water through the spiral must be maintained steady. It can be secured only when constant level bath is used. If the water is admitted direct from the tap, the rate of flow will not remain constant.

3. The rate of flow should be as small as possible so that the difference between t_3 and t_4 may be quite large. But mind it, the flow should always remain continuous.

4. To have better accuracy for the same set, determine the rate of flow for a number of times, and substitute the mean value in the formula.

5. The temperatures should be noted and water collected only when the bar has attained the steady state, otherwise the heat flowing through each section of the bar will not be the same and the formula will not apply.

6. The thermometers P and Q; and R and S should be interchanged. This will eliminate the error due to the defects if any present in thermometers.

Criticism.—The apparatus gives fairly good results. It is suitable only for good conductors of heat which can be available in the forms of cylinders.

For more accurate results, the bar should be heated by platinum resistance wire wrapped round the end A. The temperatures should be measured by platinum resistance thermometers. As the radiation losses are not totally eliminated, they cause some error.

Oral questions—

1. Define coefficient of conductivity of a substance and give its units. 2. What do you understand by the steady state of the

bar ? Is it essential to obtain it in this case ? 3. If the rate of flow of water is altered, will the steady state be disturbed ? If yes why ? 4. Why do you take thick bars and cover them with felt or cotton wool ? 5. What do you understand by temperature gradient ? 6. How is the rate of flow of water maintained constant? 7. Why the rate of flow of water is kept small ? 8. Is this method suitable for determining K for poor conductors ? 9. What is the difference between good conductors and bad conductors ?

EXPERIMENT No. 12

Experiment :—To determine the value of γ the rati *two specific heats of a gas, one at constant pressure and the* constant volume by Clement and Desorme's method.

Apparatus :—A large flask connected with a liquid man compression pump etc.

Description of the apparatus:—F is a *flask of* glass capacity (nearly of 5 litres). It is surrounded on all sides by nor

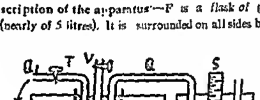

Fig. 1

ting material like cotton wool. The flask has either a metallic mou a cork is tightly fitted in its mouth. Two side tubes Q_1 and Q value V are fitted in the mouth of the flask. One of the side tubes connected to a bicycle pump through a stop cock T. The other tube Q *is connected to a manometer M. S is a vertical scale fitted to* manometer board. Generally Xylene is used as a manometric li M gives the pressure of the air enclosed in the flask. V is a valve fi in the mouth of the flask which when opened puts the inside ai communication with the outside atmosphere.

Theory—V is closed and air is compressed inside the flask by pump. Then T is closed. Due to sudden compression the temperat of the air increases. But after some time the air gets cooled to the

stationary, indicating the excess of pressure of the compressed air over that of the surroundings. If P is the atmospheric pressure, P_1 the pressure of the enclosed gas, h_1 the difference between the levels of the manometric liquid in the two limbs, ϱ the density of the liquid, and g the acceleration due to gravity, then we have,

$$P_1 = P + h_1 \varrho g \text{.....................(i)}$$

Now if the valve V is suddenly opened and closed, the enclosed air in the flask will experience an adiabatic expansion. Momentarily the air inside will attain the same pressure as out side. But due to sudden expansion the temperature of the air falls. But the temperature of the enclosed air will tend to increase and finally attain the atmospheric value. Consequently the pressure inside the flask will increase and after some time the manometric levels will again become stationary. Let this difference between the two levels in the stationary state be h_2. If P_2 now is the pressure of the enclosed gas, we have,

$$P_2 = P + h_2 \varrho g \text{.....................(ii)}$$

By considering adiabatic and isothermal changes, and simplifying, from (i) and (ii) we get,

$$\left(\frac{P_1}{P_2}\right)^{\gamma} = \frac{P_1}{P} \text{.....................(iii)}$$

Where $\gamma = \frac{Cp}{Cv}$, Cp is the specific heat at constant pressure, and Cv is the specific heat at constant volume.

By taking logs we get,

$$\gamma\ (\log P_1 - \log P_2) = \log P_1 - \log P$$

$$\text{or } \gamma = \frac{\log P_1 - \log P}{\log P_1 - \log P_2} \text{...(iv)}$$

Substituting the values of P_1 and P_2 from (i) and (ii) in (iv) we get,

$$\gamma = \frac{\log (P + h_1 \varrho g) - \log P}{\log (P + h_1 \varrho g) - \log (P + h_2 \varrho g)},$$

$$\gamma = \frac{\log\left(1 + \frac{h_1 \varrho g}{P}\right)}{\log\left(1 + \frac{h_1 \varrho g}{P}\right) - \log\left(1 + \frac{h_2 \varrho g}{P}\right)},$$

As h_1 and h_2 are much smaller than P these log series can be expanded. As the heigher powers of h are very small, retaining only the first power of h_1 and h_2 we get,

$$\gamma = \frac{h_1}{h_1 - h_2} \ldots\ldots\ldots\ldots(v)$$

Method:—1. To get rid of the moisture present in the air introduce a few drops of concentrated sulphuric acid in the flask. (These are usually put there and you need not worry about it. But you must check).

2. Connect the manometer M to the flask with the help of the side tube Q.

3. Close the valve V and connect the side tube Q, to a compression pump and compress air inside the flask. Go on compressing air till the difference between the levels of the two tubes of the manometer is nearly 5 to 10 cm. Now close the stop cock T, and wait for some time till the enclosed gas attains the atmospheric temperature. Now the two levels in the manometer will become stationary. Note down the levels of the two limbs and determine the difference h_1 between the two levels.

4. Next open the valve V and close it suddenly. The air will expand adiabatically. Its temperature will suddenly fall, and momentarily the air inside will attain the same pressure as out side. This will be indicated by no level difference in the two manometric tubes. Wait for some time till the air again attains the atmospheric temperature. The pressure will increase and ultimately it will become steady. The two levels in the manometer will again become stationary. Read the two levels and determine their difference h_2.

5. Repeat the same procedure at least for ten times. Every time note the value of h_1 and h_2.

6. Calculate γ by formula (v) for each set, and then find the mean value of γ.

Sometimes the compression pump is replaced by an exhaust pump. The procedure, however remains the same. Here, instead of air rushing out it rushes in when the valve is opened. However, [illegible]

Observations : —

S.N.	After compressing the air			After adiabatic expansion but when temperature attains intial value			
	Level in L. H. S. limb in cm. (a)	Level in R. H. S. limb in cm. (b)	Pressure difference $h_1=(b-a)$ (c)	Level in L. H. S. Limb in cm. (d)	Level in R. H. S. Limb in cm. (e)	Pressure difference h_2 (e−d)	$\gamma=\frac{h_1}{h_1-h_2}$
1 10							

Calculations:—Calculate γ from formula,

$$\gamma=\frac{h_1}{h_1-h_2}$$ by each set and then determine the mean value of γ.

Result :—$\gamma=$......(no units).

Precautions and sources of error :—1. It is very important in this experiment that the flask should be perfectly air tight. If it is not so the level will not remain stationary. In that case wax should be used and the flask should be made air tight.

2. The enclosed gas should be completely dry. Con. H_2SO_4 is therefore, placed in side the flask to absorb the moisture.

3. The manometric liquid must possess low density and low vapour pressure, so that the difference between the two levels in the manometer tubes for the same difference of pressure may be large. That is why water is never used. Xylene is normally preferred. If xylene is also not easily available some low grade Mobil oil may be used.

4. For the applicability of formula (x), h_1 and h_2 should not be very large.

5. The levels in the manometers should be noted only after the enclosed air has attained the steady atmospheric temperature.

As h_1 and h_2 are much smaller than P these log series can be expanded. As the heigher powers of h are very small, retaining only the first power of h_1 and h_2 we get,

$$\gamma = \frac{h_1}{h_1 - h_2} \qquad \text{.............(v)}$$

Method.—1. To get rid of the moisture present in the air introduce a few drops of concentrated sulphuric acid in the flask. (These are usually put there and you need not worry about it. But you must check).

2. Connect the manometer M to the flask with the help of the side tube Q.

3. Close the valve V and connect the side tube Q, to a compression pump, and compress air inside the flask. Go on compressing air till the difference between the levels of the two tubes of the manometer is nearly 5 to 10 cm. Now close the stop cock T, and wait for some time till the enclosed gas attains the atmospheric temperature. Now the two levels in the manometer will become stationary. Note down the levels of the two limbs and determine the difference h_1 between the two levels.

4. Next open the valne V and close it suddenly. The air will expand adiabatically. Its temperature will suddenly fall, and momentarily the air inside will attain the same pressure as out side. This will be indicated by no level difference in the two manometric tubes. Wait for some time till the air again attains the atmospheric temperature. The pressure will increase and ultimately it will become steady. The two levels in the manometer will again become stationary. Read the two levels and determine their difference h_2.

5. Repeat the same procedure
time note the value of h_1 and h_2.

6. Calculate γ by formula (
value or γ.

Note:—At many places, the
pump. The procedu
of air rushing out it
this procedure is
are not sure of

EXPERIMENT No. 13

Experiment:—To determine the height of a distant tower or a building with the help of a sextant.

Apparatus:—A sextant, a measuring tap (50' or 100'), a plane mirror etc.

Description of the apparatus:—Sextant consists of a graduated arc AB connected to two fixed radial arms BC and AC. The arc subtends an angle of 60° at the centre. (But on the scale 120° are marked). Each degree on the scale is marked double to make the instrument direct reading. If the mirror rotates through 5°, the scale reads 10°. CD is the third arm which is movable, and carries at one end C a plane mirror M_1 called the index glass. At the other end it carries a vernier V

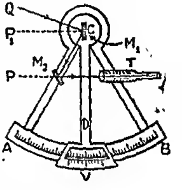

Fig. 1

which moves over the arc AB. The plane of the mirror M_1 is perpendicular to the plane of the arc, and parallel to the length of the arm C D. There are screws fixed at the back of these mirrors to set their plane perpendicular to the plane of the arc. A half silvered glass plate M_2 is fixed to the arm AC which is called the horizon glass. Its upper half is transparent while the lower half is silvered. The plane of the mirror M_2 is also perpendicular to the plane of the arc, and parallel to the arm BC. A telescope T is mounted on the arm BC which is directed towards M_2. The axis of the telescope passes through the centre of of M_2. Sometimes in place of a telescope a hollow tube with a small hole is also provided. This is of particular use when the object to be observed is not very distant. A tangent screw is also provided to make fine adjustments.

Theory:—When the arm CD occupies the position CB, the planes of M_1 and M_2 are parallel to each other. Therefore BC marks

the zero position of the circular scale AB. A wooden handle is provided with the sextant to hold it in hand. Sometimes a stand is also provided *on which the sextant can be fixed. In this position, if the telescope is* pointed towards a distant object, two images will be seen of that object coinciding with each other. One is seen through the transparent portion, while the other is due to the rays which have been doubly reflected once at M_1 and then at M_2. If the mirrors are parallel the *rays will be* parallel and consequently the two images will coincide as shown in *fig. 2. If it is not so* the instrument possesses zero error.

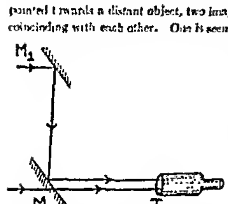

Fig. 2

Sextant is employed for determining the angular separation *between two distant points or the* angular elevation of a tower or a building. Angular separation then gives the height between the two points under consideration. Suppose the height of a tower is to be *determined. Then, a reference mark is made* at the bottom of the tower in level with the eye.

If the telescope T is directed towards this mark its image will be seen *through the transparent portion* of the plate M_2. Now the arm CD is moved so that M_1 moves and receives the rays coming *from* the top of the tower. These rays will be first reflected at M_1 and *then after getting reflected at M_2* enter the telescope and forms the image of the top. The arm CD is *so adjusted that the image of the* mark and the reflected image of *the top coincides, the angular separation of the referance mark from* top will be the $\angle$ QCP$_1$. But when the mirror turns through an angle,

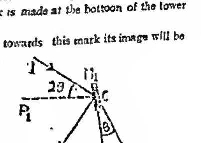

Fig. 12

the reflected ray turns through twice that angle. The angle θ through

hich the mirror is turned is measured on the scale. Naturally 2θ ll be the angular separation.

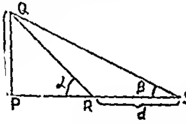

Fig. 4

Now let h be the height of the tower PQ. Let α and β be the angles subtended by the tower at the two places R and S respectively. Let the distance between R and S be d, then by simple geometry we have,

$$h \cot \beta = PR + d \text{..................(i)}$$

$$h \cot \alpha = PR \text{......................(ii)}$$

Subtracting (ii) from (i) and solving we get,

$$h = \frac{d}{\cot \beta - \cot \alpha} \text{.........(iii)}$$

α and β are determined with the help of a sextant.

hod —

To adjust the sextant — 1. Bring the arm CD near the ile of the scale, and keeping your eye near the index glass in it for the front part of the scale. If the image is in same plane as the scale, the plane of the index glass nes perpendicular to the plane of the arc. If it is not so, the screws provided at the back of the mirror, and make adjustment.

2. Observe any object through the telescope and adjust it in such ay that its two images coincide at the centre of the field ew. Now tilt the sextant so that these images lie near the of the field of view and note if they still coincide. Tilt the opposite direction so that the images lie near the site edge. If the coincidence persists, the axis of the ope is parallel to the scale, if it is not so, adjust the ope by means of the screws provided.

3. Point the sextant towards a distant object. You will see two s one direct and the other reflected one. Adjust the ble arm so that the direct image and the reflected image lie. The image which moves by moving the movable

arm is the reflected image. *If the coincidence is perfect the horizon glass is parallel to the index glass and perpendicular to the plane of the circular scale. If these two are not parallel one image will lie side ways with respect to the other.* To remove this defect *move the screws provided at the back* of M_1, so that M_1 and M_2 *are set parallel to each other*, and the two images coincide.

To determine vernier constant :—4. (a) Determine the number of divisions marked on the circular scale. Usually they are sixty, and therefore V. C. of this scale will be one minute. (b) Now determine the number of divisions on the vernier scale, they are usually four in number, therefore vernier constant of the instrument will be 15 seconds.

To determine zero reading :—5. As described in theory, make a reference mark on the building in level with your eye.

Move away from the building by a considerable distance and select some place on the ground. Mark the position of this place Let it be S (*fig*. 4). Now standing there, point the telescope towards that reference mark. Direct image of the mark will be visible through the transparent portion. Move the arm C D and get the reflected image of the same reference mark. Coincide these two images. Read the vernier and the main scale. It gives zero reading at that place. [Some times to determine the zero reading, the movable arm is so adjusted that the zero of the vernier coincides with the zero of the circular scale. After making this adjustment, the screws provided at the back of the mirrors are adjusted to bring about coincidence between the direct image and the reflected image of the reference mark at the centre of the field of view.]

6. Next point the telescope towards the reference mark so that its image is clearly visible through the transparent portion. Now rotate the arm C D so that the rays from the top falls upon the mirror M_1, and in this way obtain the image of the top in the telescope. In this position you will see two images, (a) the direct image of the reference mark, and (b) the doubly reflected image of the top. Clamp the arm CD, and by tangent screw adjust CD so that these two images completely coincide on the cross-wires. Read the vernier and the main scale and add. This gives the angular elevation of the top with respect to the reference mark. Add or subtract from it the zero reading (as the case may be). It gives the angle α.

7. Now move away or towards the mark say through a distance of 15 to 25'. Again find ut the zero reading at this place. Repeat the procedure described in step 6 and determine the new angular elevation β at this place.

8. Find out the distance between these two places with the help of a measuring tap. It gives d.

9. Knowing α, β and d determine h. It will be the height of the building from the reference mark to the top. To get the actual height, find out the height of the mark from the bottom and add it to h. This will be one set.

10. To get another set of readings change d. Take more sets if there is time and similarly determine the height of the building.

11. Determine the mean height

Observations —

[1] For the L. C. of the instrument —

(i) No. of divisions on the circular scale (x) = ...

(ii) No. of division on the vernier scale (y) = ...

(iii) L. C. of the instrument $= \frac{1}{xy} = ...0$ = ... minute.

= ... seconds.

[2] *Observation table for* α:—

S. N.	Zero reading when mark is seen				Reading when top is seen along with the mark				$\alpha = b \pm a$
	M. S. Reading	V. S. Reading	Total	Mean (a)	M. S. Reading	V. S. Reading	Total	Mean (b)	
1									
2									
3									

[3] *Similar table can be made for* β *also.*

[4] Distance between the two places (d) = ... cm.

[5] Height of the reference mark from the ground (e) = ... cm.

Calculations :— Elevation $\alpha = b \pm a$ =

Elevation β = =

Knowing α, β and d determine h by the formula,

$$h = \frac{d}{\cot\beta - \cot\alpha}$$

= ....metres.

∴ Height of the building from the reference mark (c)=...meters.

∴ Height of the building $=(c)+(e)$......................=...metres

Result —The height of the building...............=...metres.

Note—The height can be obtained in ft. also.

Precautions and sources of error:—1. It is important to note that zero error or the zero reading changes from place to place; therefore, it should be freshly determined at the place of observation.

2. The two mirrors M_1 and M_2 must be parallel to each other and perpendicular to the plane of the arc.

3. The axis of rotation of the mirror M_1 should lie at the centre of the graduated arc

4. The foot of the building and the two places of observation should lie in the same straight line.

5. The axis of the telescope should be parallel to the plane of the circular scale and must pass through the centre of the horizon glass.

Criticism:—If all the errors are eliminated, sextant gives fairly good results. To increase the accuracy in the determination of the height h, d should be large-nearly one-fourth of the height to be determined. The angles α and β should also be determined near the building and not very far off.

Modifications:-1. To determine the elevation of the sun. with the help of a sextant using an artificial horizon.

Hints:—1. Artificial horizon is a horizontal reflecting surface. It can be either a surface of mercury in a through or a carefully levelled plane mirror.

2. Place the plane mirror P on a well levelled table and look through it for the image of the sun.

3. Direct the telescope towards this mirror to look for S_1 the image of the sun. The image S_1 will be seen directly through the transparent portion.

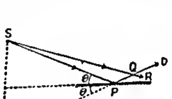

Fig. 5

4. Move the index glass so that the reflected image of the sun is also seen through the telescope. Measure this angle subtended by the

two images on the circular scale by keeping the plane of the sextant vertical. As the instrument is held above the artificial horizon, at the point of observation Q, sextant measures the angle DQR and not SPS_1 but since the object is quite distant, these two angles are almost equal and so $\angle SPS_1 = \angle DQR$. [*It is therefore always better to hold the sextant as near to the horizon mirror as possible.*]

4. As is clear from fig. (5) the elevation of the sun will be half of the angle SPS_1.

2. To determine the height of a building with the help of a sextant using an artificial horizon.

Hints—As described above, determine the angles of elevations α and β at the two places distant d apart and then calculate the required height as described in the experiment. As the observed angle differs from the angle of elevation, observations should be made from a place fairly distant from the building.

3. To determine the horizontal distance between two points at a height in level with the eye marked on the wall.

Hints :—(see Fig. 6).

1. P and Q are the two points distant l apart. Here, l is to be measured.

2. Take two points R and S in such a way, so that they are collinear with P and the line PRS may be perpendicular to AB.

Fig. 6

4. Determine the angular separations α and β between these points at R and S respectively as described in the experiment.

5. Measure the distance between R and S. Let it be d.

6. Determine l by the formula,

$$l = \frac{d}{\cot \alpha - \cot \beta}$$

7. In this case the sextant is to be held horizontally for d
mining α and β.

4. To measure height between two spots (both not in level of the eye) either both above eye level or one below and other above eye level.

Hints :—(1) Suppose both the spots are above the eye le Determine the height h_1 of one of the spots from the eye level by sextant. Similarly determine h_2 the height of the other spot from eye level. The difference between these two heights h_1 and h_2 g the height between the two spots.

(2) Suppose one is above the eye level, and the other is below eye level. First determine the height between the eye level and the s which is above. Let it be h_1. Then determine the height between t eye level and the spot which is below. Let it be h_2. h_1+h_2 gives t required height.

Oral questions:—

1. Explain the principle upon which sextant is based. 2. Wh are the adjustments of the sextant, are they necessary ? 3. What a the functions of the two mirrors ? 4. How is the instrument made dire reading ? 5. Why coloured glasses are provided with the instrument 6. Explain artificial horizon. 7. Can you measure the altitude of th sun with the help of this instrument ? 8. Explain zero error, does i depend upon the distance of the object from the point of observation If so what is the relation ? 9. What do you understand by the terms angular elevation or angular separation ?

EXPERIMENT No. 14

Experiment:—To determine the refractive index μ of glass in the form of a prism, for a given wave length of light (sodium light, $\lambda = 5893 \times 10^{-8}$ cm.) with the help of a spectrometer.

Apparatus:—A spectrometer, a sodium lamp, (or any monochromatic source of light), a prism, a reading lens, a lamp, a spirit level etc.

Description of the apparatus:—Spectrometer mainly consists of the following parts —

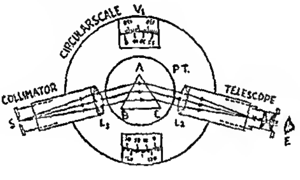

Fig. 1

(1) Collimator: It is a metal tube at one end of which is an achromatic lens system L_1 directed towards the prism table P. T. At the other end is fitted a draw tube carrying an adjustible vertical slit at its end. The draw tube can be moved in or out with the help of a rack and pinion arrangement. S is the source of light which is placed in front of the slit. The width of the slit can be adjusted by a screw. The draw tube is so adjusted that the slit lies at the focal plane of the lens L_1.

Consequently the rays emerging from the collimator are parallel. Thus, it collimates the rays. It is rigidly fixed [illegible] the base of the instrument.

(2) A circular metallic scale graduated from 0° to 360° is attached horizontally to the base of the instrument. The circular scale can rotate about a vertical axis passing through the centre of the base. A telescope is attached to the circular scale. It is also capable of rotating about the vertical axis passing through the centre of the circular scale. It rotates along with the circular scale.

Telescope is a metal tube, at one end of which it carries an achromatic lens system L_2 called the objective glass. At the other end a draw tube is fitted carrying the cross-wires and the Ramsden's eye piece. Ramsden's eye piece consists of two plano-convex lenses of equal focal lengths kept apart by a distance equal to $\frac{2}{3}$ of the focal length of any of the two lenses. Cross wire is fixed beyond these two lenses. Out of these two lenses the lens nearer the objective is called the field lens while the other is called the eye lens. The draw tube can also be moved in or out by a rack and pinion arrangement. By adjusting the draw tube telescope can be focussed to receive parallel beam of light, and form a well defined image of any object at its cross wires. The axes of the telescope and collumator are horizontal and are perpendicular to the axis of the spectrometer, and the three meet at the same point. Two screws are provided at the base of the instrument, one to clamp the telescope, and the other to give it a fine movement after clamping. The latter is called the tangent screw.

(3) At the centre, over the circular scale is mounted a base table carrying two verniers V_1 and V_2 which moves with the table over the circular scale. At the centre of the base table is placed the prism table resting on a vertical rod. In fact the base table is the part of the prism table. The prism table can be adjusted and fixed at any desired height with the help of a screw. Prism table along with the verniers is capable of rotation about a vertical axis passing through the centre of the instrument, independently of the telescope. The prism table consists of two circular plates connected by means of three levelling screws [illegible] form the three vertices

: an equilateral triangle. On the pper su face of the table parallel lines re drawn as shown in fig. 2. One set of parallel lines are parallel to the line joining the two screws. As in the case of a telescope, the prism table is also provided with two screws at the base, one to clamp it, and the other to give it a fine movement after clamping.

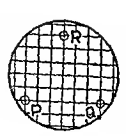

Fig. 2

Prism is placed on the prism table.

Discription of Sodium lamp:—It is an evacuated discharge tube generally U shaped in A.C. lamps filled with neon gas at a pressure of about 10mm. of mercury. A few specks of sodium are placed on its walls. Two electrodes in the form of cylinders containing tungston spirals coated with barium oxide are sealed at its two ends. When a voltage of 400 volts is applied between its two electrodes (by a step up transformer) discharge passes through the neon gas giving out its characteristic red light. Due to the heat of discharge sodium evaporates and sodium vapours are produced. The colour of light changes from red to yellow in a few minutes. As the ionisation potential of sodium is lower than that of neon, discharge is a almost maintained by the sodium vapours (at a pressure of about '01 mm. of mercury) which give out their characteristic yellow light. To maintain the temperature of the tube at about 600°C, it is surrounded by a vacuum jacket.

Theory:—ABC is the prism. PQ and RS are respectively the incident and the emergent rays of sodium light. The ∠NMS formed between these two rays is called the angle of deviation. (See fig. 3).

In the minimum deviation position, let this angle of deviation be δm. which is called the angle of minimum deviation. If μ be the refractive

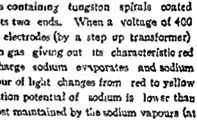

fig. 3

index of the material of the prism for this wave length of light used, and A be the angle of the prism (angle between the two refracting faces AB and AC), then μ is given by the relation,

[illegible]

[illegible]

Method – To adjust the spectrometer —

To test whether the axes of the collimator and the telescope [illegible] at a point and are perpendicular to the vertical axis about wh[illegible] the tele[illegible] and the table turn.

1. This adjustment is normally done by the manufactur[illegible] However, to test for it, mount a pin at the centre of the pri[illegible] table, and look through the wide slit of the collimator [illegible] the image of this pin formed by the collimator lens. If t[illegible] axis of the collimator is properly adjusted the image will [illegible] formed at the centre of the field of view. If not so, sligh[illegible] rotate the collimator tube about its vertical axis, so that the ima[illegible] of the pin is adjusted at the centre of the field.

Remove the eye piece from the telescope and repeat th[illegible] above procedure. If need be, rotate the telescope above i[illegible] vertical axis by the screws, to bring the image of the pi[illegible] formed by the objective glass in the centre of the field. Th[illegible] adjustment should be done at least at three different position[illegible]

and directly see the wall by the other eye. Adjust the distance between the eye piece and cross wires so that when one eye clearly observs the cross wires, the other simultaneously sees the wall. Thus the eye piece is focussed on the cross wires.

To adjust the telescope for receiving parallel rays :—4. It can be done in two ways. Put the instrument in a open window and point the telescope objective towards a well defined narrow object e. g. telegraph wires, electric cables etc. at a long distance away. By moving the eye piece with the help of rack and pinion screw so adjust, that a well defined image of the object is formed at the cross-wires without any parallax. As the rays coming from a distant object are parallel, the telescope has been adjusted for receiving parallel rays.

However, this method is not recommended as you are required to remove the spectrometer (which is a delicate and a costly instrument) from the dark room and hence there is a danger of damage to it.

To adjust both telescope and collimetor without removing it from the dark room by Schuster's method:—

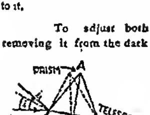

Fig. 4

5. (i) Put the sodium lamp pin in the so ket. You will find that the lamp starts glowing with reddish neon light. Wait till it starts glowing with intense yellow sodium light. (ii). Mount the prism on the table. (iii). Illuminate the collimator with sodium light (iv). Look for the refracted image of the slit through the telescope. (v). Rotate the prism so that it is set in the minimum deviation position (see step...10) shown by the dotted lines in figs. 4 and 5. The image of the slit should be quite distinct. (vi). Now slightly turn the refracting edge A of the prism towards the side of the telescope as shown in fig. 4. and look for the image of the slit in the telescope. It will be blurred, because the rays entering the telescope are oblique. (vii). Adjust the

Fig. 5

by moving the

[illegible] the image again becomes distinct. (viii) Then slightly turn the prism table so as to [illegible] minimum deviation position i.e. towards the side of the collimator. (ix) Again when seen through the telescope the image will appear to be indistinct. This time, do not disturb the telescope, but adjust the distance of the slit from the collimating lens, to again obtain a clear and a well defined image. (x). Focus the telescope again in the first position and the collimator in the second position. A few alternate adjustments will focus both the telescope for receiving parallel rays, and collimator for giving parallel rays. *Remember, when the refracting edge is moved towards the side of the telescope, it is the telescope which is to be adjusted, while if the edge is moved towards the side of the collimator it is the collimator which is to be adjusted.* If a mistake is made and the adjustments are done other way round, the image will be rendered more indistinct.

***To adjust the collimator for giving parallel rays* (when Schuster's method is not followed):—**

6. After adjusting the telescope, illuminate the slit and look for its image *directly through the telescope. As the collimator is not adjusted for parallel rays, the image formed in the telescope* will lack sharpness and definition. By adjusting the distance between the slit and the collimating lens with the help of screw provided, make the image observed in the telescope clear and well defined. *The width of the slit should be kept as small as possible. It is possible only when the slit is situated at the focal plane of the collimating lens. Thus, the collimator is adjusted for giving parallel rays.*

To adjust the prism table :—

7. (i). To start with, level the prism table with the help of a spirit level. (ii). Then, place the prism ABC so that *its centre coincides with that of the table*, and one of its refracting surface, say AC (fig. 6), remains perpendicular to the line joining the two levelling screws P and Q. *(iii). Now illuminate the slit with sodium light (iv). Rotate the prism in such a way* that light falls on the edge A illuminating both the refracting surfaces AB and A C. (v). Now fix the table. (vi). Move the telescope to see the image of the slit formed by the *rays reflected from the surface A C. If*

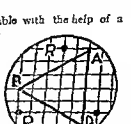

Fig. 6

slit does not lie in the middle of the field of view, or if it is much above or below the intersection of the cross-wires, adjust the two levelling screws P and Q to make it symmetrical with respect to the cross-wires.

(vii) Now turn the telescope on the other side to view the image of the slit formed by the rays reflected from the surface AB. In this case adjust the symmetry of the image with respect to cross-wires by *only* adjusting the *third screw R.* The table is now perfectly horizontal, and its edge A is vertical and parallel to the axis of rotation of the instrument.

To measure the angle of the prism (A):—8. After finishing all these adjustments, determine the least count of the verniers attached to the spectrometer. (i). Determine the smallest main scale division of the metallic circular scale. Usually it is $\frac{1^{\circ}}{2}$. (ii) Count the number of divisions marked on the vernier. Usually they are 30. Hence the least count will be $\frac{1}{2}\times\frac{1}{30}=\frac{1}{60}$ degree or 1 minute.

9. (i). Illuminate the slit with the sodium light and put the prism on the prism table. The prism is so placed, that its edge A is kept turned towards the collimator, so that half of the light from the collimator falls on the face AB, and half on AC (ii). Now turn your eye in the horizontal plane and locate the image of the slit reflected from the face AC. This helps in determining the approximate position of the image (iii). Move the telescope in that position and look for the image of the

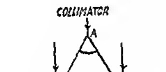

Fig. 7

t (iv). Clamp it in this position and by the tangent screw adjust its sition to obtain a sharp image of the slit on its cross-wires. Let this sition of the telescope be G (Fig. 7). (v). Note down this position the circular scale with the help of the two verniers V_1 and V_2 th a reading lens. (The difference between the readings of the two niers will be nearly 180°) (vi). Unclamp the telescope. (vii). Now n *the telescope towards the other side of the prism facing the face*). (viii). As described above again focus it on the image of the slit

formed by the rays reflected from the surface AB. Let this position of the telescope be H. Similarly determine this new position by reading the two verniers V_1 and V_2. (ix). The difference between the two readings of the same vernier taken at the positions. G and H, will give the angle through which the telescope has been rotated. Let it be 2A. As is clear from the fig. (7) half of this angle will be the angle of the prism A. To be more accurate take more than one set of readings for the two positions G and H.

Note:—Sometimes it appears difficult to obtain the reflected image of the slit simultaneously on both the sides of the prism. It happens only when (i) More light falls on one face than the other. Therefore, arrange so that light falls equally on both the surfaces. (ii), when the levelling of prism table or of telescope is not proper. So check this also.

To determine the angle of minimum deviation δm—

10. (i). Put the prism on the table in such a way that one of its refracting surfaces AB lies normal to the rays falling from the collimator. (ii). Now rotate the prism through a very small angle, so that the incident rays make a small angle at the face AB. (iii). Now look from the side of AC, and locate the approximate position of the refracted image of the slit by your eye. (iv). Move the telescope in that position, and obtain the image of the slit on its cross-wires.

Note:—Sometimes students encounter great difficulty in getting the refracted image of the slit. It is because the angle of incidence of rays falling on the face AB is very small. Therefore, to obviate this difficulty, rotate the prism in the same direction to increase the angle of incidence.

(v). Rotate the prism in the same direction and follow the image of the slit through the telescope. Due to the rotation of the prism, angle of incidence increases, decreasing the angle of deviation. Consequently to again see the image of the slit, telescope shall have to *move away from the base of the prism.* (vi). Slowly go on rotating the prism, the angle of deviation will go on diminishing. (vii) A stage will come when the angle of deviation will become minimum, and the slit will not move in the same direction, but becomes stationary for some position of the prism. (viii). Any further rotation of the prism will increase the angle of deviation and therefore, the image of the slit shall start turning back and shall move in the opposite

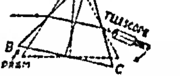

Fig. 8

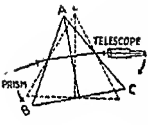

Fig. 9

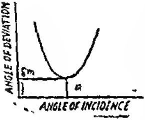

Fig 10

direction). In this position if the prism is rotated either clockwise or antic clockwise. the angle of deviation always increases, as shown in fig. (10). Consequently the image of the slit will move in the same direction, even when the table is turned in the either direction. (ix). Clamp the telescope where the image just turns back.(x). Now use the tangent screw and so adjust. that by turning the prism (in either direction), the image of the slit just reaches the intersection of the cross-wires and then turns back, (xi). This gives the position of minimum deviation. Note down this position of the telescope on the circular scale with the help of the two verniers V_1 and V_2. Let this position of the telescope be denoted by x.

11. Remove the prism, and rotate the telescope so that it directly faces the collimator. Clamp the telescope. and by adjusting the tangent screw bring the image of the slit on its cross-wires. This direct reading gives the direction of the incident rays. Determine this position of the telescope by again reading the two verniers V_1 and V_2. Let this be denoted by y.

12. Now to get the angle of minimum deviation determine the difference between the two readings of the same vernier for the two positions of the telescope, i. e. $\delta m = (x \sim y)$.

13. Rotate the prism so that now the light falls on the surface AC. In this case look from the side of AB. Repeat the whole procedure described above and determine δm.

14. Determine mean δm and then calculate μ.

Observations :—

[I] *For the least count of the circular scale:—*

(i) Value of one circular scale division $(s) = \ldots\ldots^\circ$

(ii) Number of divisions on the vernier $(n) = \ldots\ldots$

(iii) Least count $= \frac{s}{n} = \ldots\ldots$ minutes.

[2]. *Table for the determination of A:—*

S. N.	Vernier		When reflection takes place at the face AC			When reflection takes place at the face AB			Difference between the two readings of the same vernier $2A=(a-b)$	Mean 2A
			Main scale Reading	Vernier scale Reading	Total (a)	Main scale Reading	Vernier scale Reading	Total (b)		
1	V_1	1 2 3								
2	V_2	1 2 3								

[3] *Table for the determination of* δm :—

S. N.	Vernier		Reading for minimum deviation position			Reading for direct light			Difference between the two readings of the same Vernier $\delta m=a-b$	Mean δm
			Main scale	Vernier scale	Total (a)	Main scale	Vernier scale	Total (b)		
1	V_1	1 2 3								
2	V_2	1 2 3								

[4] *Similar table can be drawn when refraction takes palce from the other face of the prism.*

Calculations:—

$\angle 2A = \ldots\ldots\ldots\ldots^\circ$

$\therefore \quad A = \ldots\ldots\ldots\ldots^\circ$

Mean of $\delta m = \ldots\ldots\ldots\ldots^\circ$ Now calculate μ by the relation,

$$\mu = \sin\frac{A+\delta m}{2} \Big/ \sin\frac{A}{2}.$$

Result :— $\mu =$ (no units). (For $\lambda = 5893 \times 10^{-8}$ cm.).

Precautions and sources of error :—1 All the adjustments de ribed in the method should be properly done, otherwise the angle etermined will not be accurate. Moreover, if the adjustments ar aulty, it will be pretty difficult to obtain the images properly, an ntails great wastage of time.

2. While reading the verniers, clamp the table and the telescop otherwise a slight movement of the two will spoil the whole adjustmen lone.

3. Keep the width of the slit as narrow as possible, so that i image may be very sharp.

4. If the axis of rotation of the telescope and the table do no pass through the circular scale it will cause an error. To eliminate th error read both the verniers.

5. The voltage needed for sodium lamp is 440 volts. So be car full.

6. Once the lamp is illuminated it should be saved from all kin of jerks and movements.

7. Sometimes due to faulty polishing or some such reasons yo might get two images of the slit. Choose the brighter of the two an proceed if you are not able to investigate its cause and eliminate it.

Criticism :— The results obtained are quite satisfactory. Th accurate measurement of the angles A and δm will depend upon t good adjustments of spectrometer, and proper placing of the prism o the table.

Modification 1. To determine the dispersive power of th material of the prism with the help of a spectrometer.

Hints :—1. In this experiment replace sodium lamp by a me cury lamp. It gives almost full spectrum.

2. Adjust the spectrometer as described in the main experimen and determine the angle of the prism A.

3. Place the prism properly on the table and obtain the spectru of mercury light. Determine angle of minimum deviations for the tw extreme colours and the mean colour. To get the angle of minimu deviation for a particular colour fix the telescope in such a position, th the image of the slit through it for that colour, turns back for bo

anti-clockwise and clockwise movements of the prism. (It has been described in detail in the main experiment). Then, take the direct reading of the telescope. The difference between these two readings gives the angle of minimum deviation for that colour.

4. Similary determine angles of minimum deviation for other wave lengths. (Determine δ_m for red, violet and yellow colours). The direct reading should be taken a fresh for all colours. While obtaining minimum deviation position the prism is to be rotated, and hence the verniers may get disturbed.

5. Knowing A and the angle of minimum deviation, calculate refractive indices for each colour. As violet light is more refrangible than red, the angle of minimum deviation will be more for violet light than that of red light. Let μ_v, μ_r and μ be respectively the refractive indices for violet, red and mean yellow colour. As explained above μ_v will be greater than μ_r.

6. Knowing μ_v, μ_r and μ, calculate dispersive power by the following relation,

$$\text{or } \varpi = \frac{\mu_v - \mu_r}{\mu - 1}.$$

Where ω is the dispersive power.

Oral Questions :—

1. What do you understand by the refractive index of a material? 2. What are the factors upon which it depends? 3. What is monochromatic light? 4. What do you understand by the angle of minimum deviation? 5. How is it obtained in this case? 6. What are the main adjustments of the spectrometer and how are they done? 7. Explain the various parts of the spectrometer. 8. What type of eye piece is used in the telescope and why? 9. What do you understand by achromatic combination of lenses? 10. Why the upper surface of the prism table is ruled? 11. Why tangent screws are provided? 12. What do you understand by the dispersive power of the prism? 13. What type of spectrum you get by a mercury lamp? 14. Though sodium light gives two wave lengths we see only one line in this experiment, why? 15. Why the glow is reddish in the beginning in a sodium lamp? 16. Why neon is used and why is it excited earlier to sodium when its ionisation potential is higher?

EXPERIMENT No. 15

Experiment :—To determine the magnifying power of a telescope.

Apparatus :—The telescope whose magnifying power is to be determined, a scale with well defined graduations quite wide apart (preferably 4 cm. apart), measuring tap etc.

Description of the apparatus :—For the description of telescope, see experiment no. 14.

Theory :—Let PQ be the object and P'Q' be its image formed by the objective of the telescope. Let the eye piece form the final

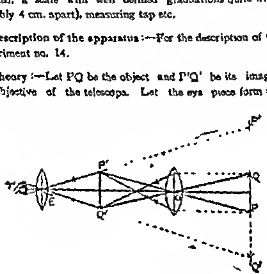

Fig. 1

image P''Q'' at the same place where the object PQ lies. As the length of the tube is quite negligible in comparison to the distance of the object from the eye, the angle subtended by the object at the objective may be taken to be equal to the angle subtended by the object at the eye. Let m be the magnifying power of the telescope, then, we have,

$$m = \frac{\angle P''EQ''}{\angle POQ} = \frac{P''Q''/d}{PQ/d}$$

$$= \frac{P''Q''}{PQ} \quad \text{.................(1)}$$

Where d is the distance of the object and the image from the telescope.

Suppose the object is a graduated scale placed in the position of the object PQ. If N divisions of the scale (i. e. divisions in the length P″Q″) as viewed directly by one of the eye coincides with n divisions of the scale (i. e. divisions in the length PQ) as seen through the telescope with the other eye, we have,

$$m = \frac{P''Q''}{PQ} = \frac{N}{n} \text{.........(ii)}$$

Method :—1. Place the given scale vertically at a distance of nearly 20′ from the telescope. The distance selected should be such that the divisions marked on the scale may be distinctly visible through the naked eye.

2. Directly see the scale with one eye, and with the other eye, look for the image of the scale through the telescope. Adjust the distance of the objective from the eye piece in such a way, that the final image P″Q″ (fig. 1) is formed at the same distance as the scale, i. e. the image of the scale lies by its side, and there is absolutely no parallax between the directly observed scale and its image seen through the telescope.

3. Now concentrate your attention on a convenient portion of the scale, say, PQ as seen through the telescope. Count the number of the divisions on the scale in this portion i. e. between P and Q. It gives n.

4. Now look through the naked eye, for that portion of the scale which coincides with the portion PQ as seen through the telescope. Let it be P″Q.″ Consequently P″ and Q″ will respectively coincide with Q and P. Determine the number of divisions on the scale in the portion P″Q″, as seen through the naked eye. This gives N.

5. Find the distance of the scale from the telescope.

6. Repeat the above procedure, and take readings for N and n for three times.

EXPERIMENT No. 16

Experiment:—To determine the value of horizontal component of earth's magnetic intensity at a place, using deflection and vibration magnetometers.

Apparatus :—A vibration magnetometer, a deflection magnetometer, a bar magnet, a stop-watch, a brass rod, a compass needle, a spirit level, a meter scale etc.

Description of the apparatus :—You are already very well familiar with these two types of magnetometers. The vibration magnetometer is shown in fig. 1, while the deflection magnetometer is shown in fig. 4

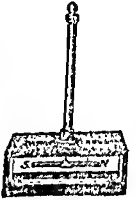

Fig. 1

Theory —(a) If a magnet of magnetic moment M is freely suspended in the earth's horizontal field H and allowed to vibrate, it oscillates simple harmonically. It is due to the restoring couple MH Sin θ as shown in fig. (2). If T is the periodic time of the magnet. It is given by,

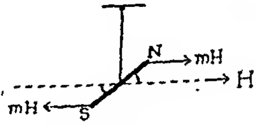

Fig. 2

$$T = 2\pi\sqrt{\frac{K}{MH}}.$$

Where K is the moment of inertia of the magnet about an axis passing through its centre of gravity.

(b) If the same magnet is placed on the arm of a deflection magnetometer set in tan A position, the former will produce a magnetic field at the centre of the compass box. Let this field be F. Under the influence of the two fields F and H acting at right angles to each other,

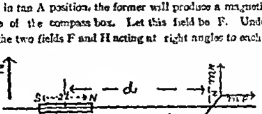

Fig. 3

the compass needle placed at the centre of the box will be deflected. In equilibrium, let the needle make an angle θ with the direction of H, then we have,

$$F = H \tan\theta$$

But F in tan A position $= \frac{2Md}{(d^2-l^2)^2}$

$$\therefore \qquad \frac{2Md}{(d^2-l^2)^2} = H \tan\theta$$

$$\text{or} \qquad \frac{M}{H} = \frac{(d^2-l^2)^2}{2d} \tan\theta \ldots\ldots(ii)$$

Where l is half the effective length of the magnet, and d is the distance of the middle point of the magnet from the pivot of the compass needle. Dividing (i) by (ii) we get,

$$H = \sqrt{MH \div \frac{M}{H}} = \sqrt{(i) \div (ii)} \ldots\ldots(iii)$$

$$\text{and} \qquad K = W\frac{L^2+B^2}{12} \ldots\ldots\ldots\ldots(iv)$$

Where W, L and B are respectively the mass, length and breadth of the magnet.

Method.—**To adjust the vibration magnetometer** :—1. Level the instrument by levelling screws. When it is in level, the suspension thread will pass through the centre of the hole, without touching the sides.

2. Put the magnetometer in the magnetic meridian; usually a line is marked on the horizontal mirror of the magnetometer or a thread is stretched. Keep a compass needle on it and rotate the box till the needle is parallel to the linear thread. Draw the boundary line round the box. If no line or thread is provided, draw the magnetic meridian with the help of a compass needle, and place the longitudinal edge of the magnetometer along it.

3. There should be no twist in the suspension when a magnet is put in the stirrup. The stirrup should remain pointing in north south direction. To achieve this, put a brass rod in the stirrup and see that brass rod comes to rest in the magnetic meridian. If it does not, rotate the upper screw head till the rod is in the magnetic meridian. The brass rod may take a long time to come to rest and therefore, for this adjustment see that the brass rod equally deflects on both sides of the meridian. Always keep your eye vertically above the box.

To determine T :— 4. Remove the brass rod, and gently put the given bar magnet on the stirrup. Bring the magnet to rest by stopping any kind of motion by hand. Close the box.

5. Bring one end of any other magnet from out side near one of the ends of the suspended magnet, till the latter is slightly rotated from its position. Remove the second magnet, and allow the suspended magnet, to oscillate about its centre of gravity.

6 Start the stop watch when the magnet crosses the mean position say from left to right. When it again crosses the mean position from left to right, it is said to have completed one oscillation. Determine time for 15, 20, and 25 oscillations respectively. Find time for one oscillation from each observation, and then determine mean periodic time T.

7. Find the length (L) and breadth (B) of the magnet by a meter scale, and its mass (M) by a physical balance.

To set the deflection magnetometer in tangent A position:— 8. Rotate the compass box which is kept on the wooden board till the line joining 0-0 division of the circular scale is in line with the length of the scale (along the line marked on the scale).

9. Level the compass box with the help of a spirit level.

10. Now rotate the arms of the magnetometer (wooden board) without disturbing the compass box till the pointer comes on 0–0 reading.

this case the pointer will be parallel to the arms, and the needle will perpendicular to the arms. H will be acting perpendicular to arms.

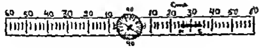

Fig. 4

for safe guard mark the position of the arms so that any distur ce from the set position may become apparent.

To determine the deflection θ :—11. Take the same magne l in the vibration magnetometer) and place it length wise along say arm of the magnetometer, such that its geometrical axis produce s through the pivot of the needle. Adjust the magnet in such that the deflection is near about 45°. Note this distance (d) of th le point of the magnet from the pivot of the compass needle. Not eflection of both the ends of the pointer. This gives θ.

12. Reverse the face of the magnet keeping other things sam read both the ends of the pointer. This makes four readings.

13. Reverse the magnet pole to pole and keeping the distan note both the ends of the pointer.

14. Reverse the face of the magnet and again read both ends inter. This makes eight readings.

15. Place the magnet on the west arm at the same distance, ar the above procedure taking eight readings as explained above.

16. Take mean of these sixteen readings. This gives θ. Ta ets of observations for θ after changing d, if there is time, othe lly one set will do.

7. Find the value of M H by formula (i)

. Determine the value of $\frac{M}{H}$ separately for every set and fi alue of $\frac{M}{H}$ using formula (ii).

Find the value of H by formula (iii).

Observations :—

[*1*] *Table for vibration magnetometer* —

S. N.	Time for oscillations in sec.			Time for one oscillation in sec.			Mean T in sec.
	15	20	25	I	II	III	

(i) Length of the magnet =.........cm.

(ii) Breadth of the magnet =.........cm.

(iii) Mass of the magnet =.........gm.

[*2*] *Table for deflection magnetometer.*

S. No.	Distance of the magnet *d* in cm.		Magnet on west arm								Magnet on east arm								Mean θ	tan θ
			N-pole towards east				N pole towards west				N-pole towards east				N-pole towords west					
			Face A up		Face A down		Face A up		Face A down		Face A up		Face A down		Face A up		Face A down			
	one end	other end	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II		
1																				
2																				
3																				

Calculations :—

1. MH =............

2. $\frac{M}{H}\begin{cases} 1. = \\ 2. = \\ 3. = \text{............} \end{cases}$

3. Mean $\frac{M}{H}=$

4. H 　　=................gauss.

Precautions and sources of error :—

[A] For deflection megnetometer :—

1. Reading should be taken without parallax i. e. keeping the head vertically above the pointer so that while taking the readings, the image of the pointer in the plane mirror may lie exactly below the pointer.

2. All magnetic materials should be removed away from the magnetometer.

3. The magnet should be placed so that its magnetic axis when produced should pass through the pivot of the needle. If this is no so the eight readings obtained for θ in the method will be much removed from the mean value.

4. Before noting the deflection tap the compass box gently.

5. The distance should be so adjusted that the deflection of the needle is near about 45°. In the neghbour hood of 45° the percentage error made in reading the deflection is considerably reduced.

6. For greater accuracy d should be kept fairly large compared to l, so that in determining (d^2-l^2), the percentage error is reduced. Because it is very difficult to find out exactly half the effective length l of magnet.

7. The needle may not be pivoted at the centre of the circular scale. To correct for this eccentricity, both ends of the pointer are read.

8. The geometric axis and magnetic axis of the magnet may not coincide, hence, the face of the magnet is reversed pole to pole.

9. The poles of the magnet may not be symmetrically situated. To eliminate this error the magnet is reversed pole to pole.

10. Zero of the linear scale may not coincide with zero of the circular scale; that is why readings are repeated on the other arm.

[B] For vibration megnetometer :—

11. It is necessary to suspend the magnet in such a way that its centre of gravity may lie exactly below the suspension, and the magnet may remain perfectly horizontal. This is done by providing a stirrup arrangement.

12. Look vertically downwards to count the number of oscillations.

13. The amplitude of the oscillations must be very small (Below 5°, so that $\sin\theta = \theta$).

14. Remember that the *length* and *breadth of the magnet are* the two sides perpendicular to the axis of suspension. Don't confuse breadth with thickness of the magnet.

15. The magnet must *perform vibrations* in a *horizontal* plane without tossing up or down.

17. *For greater accuracy, the suspension fibre must be free from* tortonal reaction. Hence the suspension should have no initial twist. That is why horse hair is preferred.

Criticism *:—The value of H obtained by this method is not completely accurate due to the following reasons.*

(1) *It is very difficult to determine accurately the effective length l of the magnet. If d is increased θ will not remain 45°, therefore it is difficult to satisfy these two conditions simultaneously.*

(2) *The friction at the pivot of the needle is not completely removed, it causes an error in the measurement of the deflection.*

(3) *The length of the needle is not sufficiently short, therefore, it is not perfectly justified to assume that the needle is moving in a uniform field* Thus *tangent law cannot be rigourously applied.*

(4) *The moment of inertia of the stirrup cannot be completely neglected as is done in derving the theory*, hence error is introduced.

(5) *Furthermore, the suspension* fibre is neither completely free *from tostional reaction*, nor it is intially twist-less.

Therefore, if greater accuracy is the aim, Kew magnetometer should be employed.

Modification :—To determine the magnetic moment M of a magnet.

Hints :—Find the value of $\frac{M}{H}$ and M H as shown above. Multiply *the two to get the value of* M^2, and hence determine M.

Oral questions :—

1 *Explain total intensity of earth's magnetic field*, its horizontal

and magnetic meridian. 2. Why do you use H and not I in the experiments of deflection and vibration magnetometers? Why this method is called absolute method? 4. Is this method accurate? 5. Define magnetic moment and pole strength of a magnet. 6. Why is magnetic needle made small, while the pointer is longer? 7. Why the pointer is made of alluminium? 8 Can it be made from iron? 9. Why is the mirror provided in the box? 10. What is the necessity of taking sixteen readings? 11. What is a tangent law, and how is it made use of in this experiment? 12. How do you set a deflection magnetometer in tan A or tan B position of Gauss? 13. Which position is preferable and why? 14. Why should the deflection be adjusted in the vicinity of 45^{o}? 15. What is simple harmonic motion? 16. Explain moment of inertia. 17. Why stirrup is used for placing the magnet? 18. Why is it made so light, can you suspend the magnet from the suspension thread, instead of putting it in a stirrup? 19. Why is it necessary to remove the twist in the suspension? 20. What type of suspension is preferred and why? 21. Can you take a cotton thread? 22. Why should the magnet oscillate in a uniform magnetic field? 23. Why a brass rod is used to remove the twist? 24. Why the magnet should remain perfectly horizontal? 25 Why the amplitute of vibratons should be small? 26. Will the period of oscillation alter if the magnet is rotated by 9^{o} i. e. breadth becomes depth?

ELECTRICITY

General Instructions :— Electrical experiments are easy to perform, providedly they are done in a *proper way*. To achieve efficiency and avoid difficulties, the following points must be kept in view during their performance.

1. Before the commencement of the experiment, it is very essential for you to draw a neat circuit diagram showing clearly the different connections. Keep this diagram in front of you and accordingly arrange the apparatus on the table. In no case it is advisable to depend upon memory.

2. Make sure that the various instruments which you would use in a particular experiment are of the *proper range*.

3. After putting the apparatus properly on the table, see that the connecting wires used to connect them are not *too long*. Their lengths should be just necessary. Make their ends naked and clean them. Connect these ends to the instruments tightly. It is extremely important to verify that the connections made are properly *tight*. If the connections remain loose, it is possible that the instruments may not give deflection.

4. *Look to it that the connections may not become jumbled up at any place. Connections must be clearly distinguishable on the table. If there is more than one circuit, all the circuits should be clearly distinguishable. This precaution will very much facilitate to trace the faults, if there are any.*

5. *Always use a key in the circuit. Pass current in the circuit only for a short interval of time i. e. when you are taking observations.*

6. See that the instruments which you are using may not get damaged due to the flow *of excessive currents through them*. There fore while passing current through the circuit do not *forget the range* of the various instruments connected in the circuit. While using a galvanometer, always put a shunt across it in the beginning. Remove the shunt only when the current passing through the galvanometer [illegible]

7. When it is necessary that the current flowing in the circuit should remain steady, use such batteries which possess constant e. m. f., and have large capacities (e. g. storage batteries). In circuits where steady currents are not necessary, primary cells may be employed [it is due to this reason that we employ Leclanche cell in experiments on Post-office box and Careyfoster's bridge].

8. While using a resistance box, see that the plugs in the gaps *are tight.*

9. To change the resistance in the circuit always use a rheostat, and not a resistance box.

10. Before starting the experiment see that the batteries or the cells which you are using possess the necessary e. m. f. or not.

Description of the apparatus :—

1. **Keys :—**The current can be stopped or started in the circuit with the help of keys. They are of two types (i) plug keys (ii) tap keys. In case of plug keys, a plug has to be inserted in the gap to start the current There are one, two, three or four plugs keys. A four plug key is used as a reversing key. Keys are generally represented in diagram by the symbol K. A tap key has to be pressed to complete the circuit.

2. **Reversing key or commutator :—**It has four terminals two fixed and two movable. The movable terminals can alternately be put in contact with the fixed terminals. It is employed to reverse the direction of the current in the circuit.

3. **Moving coil galvanometers** (*Suspended coil type*) :—

Description :—It consists of a permanent horseshoe magnet NS. The pole pieces of the magnet are concave having a cylindrical air gap in between them. A coil of insulated copper wire of many turns is suspended between them. The coil is either rectangular or circular in shape. It is suspended by means of a phosphor-bronze strip A fixed to the torsion head H forming one of the terminals of the instrument.

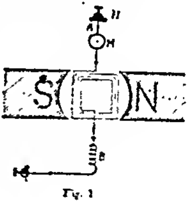

Fig. 1

Phosphor bronze is chosen because it is good conductor and its coupl per unit twist is small. The current enters the coil through thi strip. The other end of the coil is connected to a coiled hair sprin B, also of phosphor bronze. The spring is connected to th other terminal of the instrument. Current leaves the galvanomete through the spring. The spring and the strip provide the controlling couple. The strip carries a mirror M. By lamp and scale arrangement the deflection of the mirror can be found out.

Usually a soft iron core of spherical or cylindrical shape as shown in fig. 2 is fixed at the centre of the coil. This concentates the lines of force in the coil *increasing the controlling field and making it more radial.* The pole pieces are made concave or circular to make the field *radial* as shown in fig. 2. The coil is so suspended in the air gap that the magnetic lines of force due to the permanent magnet are parallel to its plane. As the field becomes radial, the lines of force always remain parallel to the plane of the coil so long the coil rotates in the vertical plane. *The coil may lie in any position, the lines will always cut its vertical sides at right angles.*

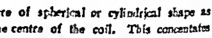

fig. 2

Adjustments :—The instrument is carefully levelled so that the coil is free to rotate in the magnetic field.

Working:—When a current is passed through the coil, equal forces act on its two sides in opposite direction. These two forces together constitute a couple which is called *a deflecting couple.* This *tends* to set the coil at right angles to the direction of the magnetic fielp (field due to the magnet). On the other hand the tortion present n the phosphor-bronze strip opposes the motion of the coil and generates *another couple.* This is called the *controlling couple. Under the influence of thes two couples, the coil sets in an intermediate position where the moments due to both of the couples are the same.* The deflection of the coil is measured by lamp and scale arrangement.

Theory:—Let H be the field due to the permanent magnet, i the strength of the current passing through the coil. l the length of the vertical side of the coil, b the breadth of the coil and n the number

of turns of wire in the coil. When current passes through the coil each of its vertical sides experiences a force equal to $H\,i\,l$ dynes. As there

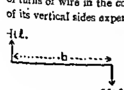

fig. 3

are n turns, the total force experienced is equal to $H\,i\,l\,n$. These two forces act in opposite direction and the perpendicular distance between them is b. This is strictly true in the deflected position for a galvanometer in which the pole pieces are concave and the field is radial.

Then, the moment of the deflecting couple $= n\,i\,H\,l\,b$.

If θ is the deflection and T is the moment per unit twist generated in the suspension strip, the moment of the restoring couple is $= T\theta$. In equilibrium the two moments of the couple are equal.

$$\therefore \quad n\,i\,H\,l\,b = T\,\theta$$

or $$i = \frac{T}{n\,H\,l\,b}\,\theta \quad [\text{but } l \times b = A \text{ the area of the coil}]$$

or $$i = \frac{T}{n\,H\,A}\,\theta$$

or $$i = k\,\theta. \quad \left[\text{where } k = \frac{T}{n\,H\,A}, \text{ as } T, n, H \text{ and } A \text{ are constants, and } k \text{ is a constant}\right]$$

This is called the constant of the galvanometer.

Hence $\quad i \propto \theta$

Thus the current passing through the coil is directly proportional to the angle of deflection. If k is known, i can be calculated.

Sensitiveness of a moving coil galvanometer :—From relation $i = \frac{T}{n\,H\,A}\,\theta$, we know that for the same value of i, θ is large when k is small. For k to be small, T should be small and n, H and A should be large. If A and n are very much increased, the resistance of the instrument increases too much. Hence, to increase sensitiveness T is decreased and H is increased. As phosphor bronze has more tensile strength and smaller value of T, it is extremely suited for using it in suspending the coil. In better types of galvanometers quartz suspension coated with a conducting layer is used. Such a suspension has a very low value of couple per unit twist. H is increased by taking a more powerful magnet. The strength of the

magnet is increased by special processes which are a commercial secret and by making it in laminae from. Addition of a soft iron piece at the centre of the coil helps also in increasing H.

As this form of galvanometer was first of all developed by D'Arsonval, it is also called **D'Arsonval galvanometer.** It is very sensitive. It can measure currents up to 10^{-9} amp.

Damping of a galvanometer :—Even when current ceases to pass, the coil does not come to rest quickly. In order to, make it dead beat, *i. e.*, in which the coil comes to rest quickly, its oscillations are damped. *It is done by winding the coil upon a light conducting frame.* The induced *eddy currents* produced in the frame oppose the motion of the coil, and brings it quickly to rest.

4. Moving coil galvanometer, pivoted type :—In this case a coil of copper wire is wound upon an alluminium frame. Instead of suspending the coil, it is pivoted by means of a spindle fixed in bearings. The coil is placed between the two concave pole pieces of a permanent magnet NS as shown in fig. 5. The coil is so pivoted that its plane always remains parallel to the magnetic field. At the centre of the coil *an iron core is fixed which concentrates the field within the coil.* One end of the coil is connected to a hair spring placed above the coil. The other end of the hair spring is connected to one of the terminals of the instrument. Similary, the other end of the coil is connected to the other hair spring placed below the coil. The other end of this spring is connected to the second terminal of the Instrument. The two springs are coiled in opposite direction. *They provide the controlling couple to balance the deflecting couple.* [See Fig. 6]. A light pointer attached to the spindle of the coil, at right angles to its plane. The pointer moves over a circular scale calibrated in parts of equal length. The principle of working of this instrument is exactly the same as in the case of suspended type.

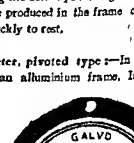

fig. 4.

Though the pivoted type of galvanometers are a bit less sensitive than the former type, they are *portable and dead beat*. The pointer quickly

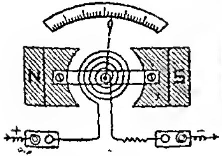

fig 5'

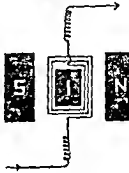

fig. 6

comes to rest. They are generally employed in all electrical experiments.

5. Ammeter. It is a moving coil pivoted type galvanometer with the difference that a low resistance shunt is put across the coil of a galvanometer. It is used to measure current. The shunt serves two purposes.

(i) It diverts most of the current from the galvanometer and so only a *fraction of the main current passes through the latter* (ii) It reduces the equivalent resistance of the system formed by the galvanometer and the shunt. *Thus, an ammeter has an extremely low resistance. Theoretically speaking, it is zero.* The circular scale is calibrated in amp. or milli amp. by some standard current measuring instruments. The pointer rests on zero, marked on the left hand side of the scale. It moves towards right when a current is passed through it. Actually, if one amp. current is flowing in the circuit a small fraction of it enters the coil which gives deflection. This deflection is called one amp. and so on. Thus it is calibrated

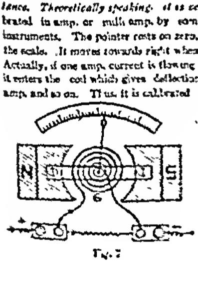

Fig. 7

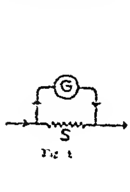

Fig. 8

resistance and low temperature *coefficient.* The wire for reasons al ready given is either of constantan or *manganin.* The wire is wound on a *non-conducting* cylinder, generally of china clay. Each turn is insulated from the other. A sliding contact S slides over the *cylinder and* makes contact with naked portion of the wire. C is a terminal connected to the thick rod along which S moves. If A and C are connected in a circuit, and if the current enters the rheostat at A, it passes *through the wire between* A and S and leaves at C. *It does no flow* between S and B. *If* S *is moved towards A, the current passes through* lesser and lesser number of turns. Consequently, the resistance decreases and current increases. In stead of this, if S is moved towards B, more resistance is introduced in *the circuit* and *the current decreases. Similarly,* if B and S are connected in the circuit, current passes through BS. By moving S towards B, the resistance in the circuit decreases and *vice versa.* If A and B are connected in a circuit, it behaves as a *fixed resistance.* On the top of the instrument is usually written something like 22 ohms. 2·5 amp. It means that the maximum current which can be passed through the rheostat is 2·5 amp. without *damaging it. If current exceeds 2·5 amp., coil will be burnt off* due to excessive heating. 22 ohms denote the maximum resistance it can offer when connected between A and B.

Rheostat

Fig. 13

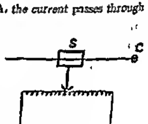

Fig. 14

9. **Hot wire ammeter** :—When an electric current flows through a metallic wire, heat is produced, and consequently *it expands. The elongation so produced has been utilised to measure currents* in a hot wire ammeter. The current which is to be measured is allowed to flow through a fine wire (of platinium-iridium alloy of about 0.1 mm. diameter) stretched horizontally. At the middle of this wire is attached another wire of phosphor-bronze. The other end of the latter is attached to an unspun silk thread. The silk thread after passing round a pully is fastened to a spring fixed in the instrument. The spring keeps the wire taut. The pulley is mounted over a spindle, the latter carries a pointer which moves over a circular scale.

plate. This is on account of ***chemical affinity*** existing between the ions and the plates. Ions are not neutral atoms but parts of atoms carrying either a positive or a negative charge. The agency which does the work of moving these ions within the cell is called the electromotive force. This comes into existence on account of *chemical reactions.* Thus, within the cell the positive charge moves from zinc to copper plate giving rise to an electric current. As explained above, this current which flows from zinc to copper within the cell is due to the electromotive force. It remains constant so long as the solution and the plates are the same.

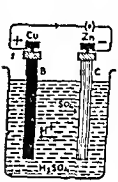

Fig. 15

current ultimately stops. ***This defect is known*** as polarisation. This can be explained in two ways—

(a) The layer of neutral gas formed around the positive plate offers a great resistance to the current within the cell. As the thickness of the layer increases, the resistance also increases. Ultimately it becomes so high that the current totally stops flowing within the cell.

(b) As the fresh incoming hydrogen ions carrying positive charge cannot reach the copper plate, they hand over their charges to the neutral layer. Thus, an electric field is set up between the layer of hydrogen and zinc plate. This is called *back electromotive force*. It tends to send current in the opposite direction. If it becomes quite high, it completely impedes the motion of hydrogen ions towards the copper plate. It results in the stoppage of the current within the cell.

Polarisation can be removed by preventing the formation of hydrogen layer around the plate. This can be done in two ways— (i) *mechanical* and (ii) *chemical*. In mechanical method we have to use a mechanical device like a brush to remove the hydrogen layer. But this is not very efficient. In chemical method we oxidise hydrogen as soon as it is formed. Different oxidising agents have been employed in different cells. *The chemicals which are used to remove hydrogen in these cells are called* **depolarisers**

(ii) **Local action:**—Pure zinc does not react with sulphuric acid unless a contact is established between zinc and copper. Certain impurities, *e. g.*, carbon, arsenic, iron, lead etc. are always present in ordinary zinc used in making zinc plates. These impurities act with acid forming miniature cells consisting of impurity, acid and zinc. *These miniature cells so formed cause local currents to flow in the zinc rod.* This unnecessarily consumes the zinc rod because the local currents so formed do not contribute to the main current. *This is a sheer wastage of zinc and is known as* **local action.**

This defect can be remedied by *coating the zinc rods with a mercury layer.* This process is known as *amalgamation of zinc.* Zinc dissolves in mercury and comes on the surface layer, while the impurities remain inside the mercury coating. Thus, the contact between the two is broken. This stops the local action.

Cells:—Following are a few important primary cells. Each one of them has a different polariser and a different electrolyte.

12. Leclanche Cell :—

Construction—It consists of a glass vessel containing a solution of ammonium chloride (*NH_4Cl*). A porous pot is placed in the *middle of the vessel. A carbon rod is* placed at the centre of the pot. Powdered *manganese dioxide (MnO_2) mixed with* pieces of carbon is packed around the rod *in the porous pot. A zinc rod is immersed* in the solution. Carbon and zinc respectively *forms* the positive and *negative* plate of the cell. The electrolyte is *NH_4Cl.*

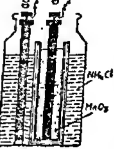

fig. 16

Work ng--Zinc acts with ammonium chloride forming zinc chloride and *positively charged ions of hydrogen*

$$Zn + 2NH_4Cl = ZnCl_2 + 2NH_3 + 2H$$

The ions penetrate through the porous put and carry the charge to the carbon rod. The potential of the carbon rod increases, *MnO_2* acts as a depolariser. It acts on hydrogen forming water.

$$2MnO_2 + H_2 = Mn_2O_3 + H_2O$$

Being a solid, it is a *weak oxidising agent* and is, therefore, unable to remove hydrogen quickly. Therefore, the cell gets polarised after a little use. But, if, some rest is given to the cell, the deposited hydrogen is converted into water and the cell starts working again. Thus this type of cell is suitable only for those functions where *intermittent current is needed e. g.* in telegraphs, telephones, electric bells etc. It is quite cheap and sturdy. *Its e. m. f.* is 1'45 volts. The local action is eliminated by amalgamating the zinc rod.

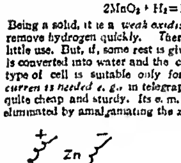

fig. 17

13. Daniell Cell :—

Construction :—It consists of a copper vessel filled up with concentrated solution of copper sulphate. The copper vessel acts as the positive plate. *In the* middle of the vessel is placed a *porous pot* containing dilute sulphuric acid and an amalgamated zinc rod. The zinc rod *forms* the negative plate.

Working :—*Zinc reacting with H_2SO_4 forms $ZnSO_4$* and hydrogen. Positive ions of hydrogen are liberated in this reaction and the potential of the zinc plate is lowered.

$$Zn + H_2SO_4 = ZnSO_4 + 2H^{+}$$

The hydrogen ions so produced travel towards the copper vessel reacting with $CuSO_4$. **Copper Sulphate Solution acts as a depolariser.**

$$CuSO_4 + 2H^{+} = H_2SO_4 + Cu^{++}$$

Neutral solution of sulphuric acid is formed and positively charged ions of copper are liberated. The ions travel towards the copper vessel. They give charge to the vessel, and are deposited. Thus, the potential of the copper vessel increases. The e. m. f. of this cell is 1 1 volt. The liquid depolariser used is better than the solid depolarisers. Therefore, the cell is almost free from polorisation. Local action is eliminated by amalgamating the zinc rod. *This type of cell can be used where steady current is to be drawn.*

14. Bunsen's Cell :—

Construction:—It consists of a porous pot filled with concentrated solution of nitric acid. A carbon rod is placed in the pot. The rod acts as the positive plate of the cell. The porpous pot is placed in a larger procelain vessel containing dilute solution of sulphuric acid. An amalgamated zinc cylinder is placed between the vessel and the porous pot. It remains immersed in H_2SO_4, and acts as the negative plate.

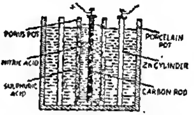

Fig. 18

Working :—The reactions take place in H_2SO_4 while HNO_3 acts as a *depolariser.*

$$Zn^{++} + H_2SO_4 = ZnSO_4 + 2H^{++}$$

Zinc reacts with H_2SO_4 forming $ZnSO_4$ and positive ions of H_2 are liberated. These ions travel through the porous pot acting with HNO_3

$$HNO_3 + H_2^{++} = H_2O + NO_2^{++}$$

Molecules of NO_2 carry the positive charge to the carbon rod. and the potential of the rod increases. NO_2 dissolves in concentrated HNO_3. This cell is not much in use because the fumes of NO_2 are very injurious and disagreeable. Its e.m.f. is 1.95 volts. Polarisation is also not completely removed in this cell.

15. **Grove's cell** :—It is exactly similar to that of Bunsen's, except that the carbon rod is replaced by a *platinum foil. It is not in common use.*

16. **Bichromate cell** :—**Construction.** *It consists of a glass bottle containing dilute solution of* sulphuric acid. A few crystals of potassium dichromate are placed in the acid. The crystals of potassium dichromate act as a *depolariser.* Two inter-*connected carbon plates cc are placed in the* bottle as shown in *fig.* 19. The plates act as the positive plate. A zinc rod forming the negative plate is placed between the *carbon plates*

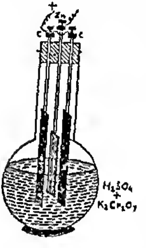

Fig. 19

Working:—Zinc reacting with H_2SO_4 *forms* zinc sulphate and hydrogen ions

$$Zn + H_2SO_4 = ZnSO_4 + 2H^{++}$$

The positive ions of hydrogen so liberated hand over their charge to the carbon plates. They are converted into water by the depolariser $K_2Cr_2O_7$. Actually *it is* the chromic acid formed which acts as a depolariser. Its e.m.f. is 2 volts.

As the depolarisation is not complete, the current falls off soon *It is employed only when strong currents are required for a very short duration.*

17. **Standard cells** :—As the current is drawn from the cells described above, generally their e.m.f.s. decrease. Therefore, they can not be used where constant *e.m.f.* is required. Hence, for calibration and comparison purposes standard cells are required. *Their e.m.f.s* remain constant and do not change with temperature. They are used only for calibration purposes. They are mainly of two types:—

(1) **Cadmium cell**:—**Contruction** :—It consists of two limbs made up of glass joined by a horizontal tube as shown in *fig.* 20. *It* forms a H shaped vessel. Pure and dry mercury is placed at the bottom of *one of the* limbs. It acts as the positive pole. Above the level of mercury paste *of mercurous sulphate is placed* which acts as the depoloriser. At the bottom of *the other limb an amalgam of mercury*

and cadmium is placed which acts as the negative pole. In the vessel, saturated solution of cadmium sulphate is filled in. The level of the solution in the vessel is kept a little above the horizontal tube. To ensure the saturation of cadmium sulphate solution, crystals of cadmium sulphate are placed as shown in fig. 20. Two platinum wires are fused at the bottom of both the limbs. Its e.m.f. is 1·0183 volts at 20°C. Current is never drawn from this cell. It is mainly used for comparison purposes only.

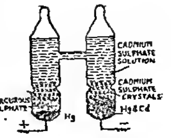

Fig. 20

(2) **Latimer Clarke cell** :—It is similar to cadmium cell except that cadmium is replaced by zinc through out. It is often shaped like dry cells.

18. **Dry cells** :—They are nothing but modified forms of Leclanche cells. They are extensively used in torch lights, radios, etc. Every body is quite familiar with these types of cells.

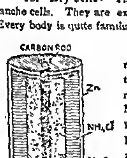

Fig 21

Construction :—It consists of a carbon rod to which is attached a brass cap. It forms the positive pole. The rod is placed in a muslin bag containing powdered charcoal, MnO_2 and a little gum. Around the bag is placed a paste of NH_4Cl, saw dust and a little zinc chloride in a zinc container. The zinc container forms the negative plate of the cell. A non conducting diaphragm is placed at the bottom and the top of the container to insulate it from the carbon rod. To allow the ammonia gas to escape, outlets are provided in the muslin bag. The e.m.f. of this cell is 1·4 volts.

Internal resistance of a cell :—When a current passes through a cell, it has to pass through the electrolyte constituting that cell. The electrolyte offers certain amount of resistance to the passage of the current through the cell. *This resistance is called the internal resistance of the cell.* It varies from cell to cell. *The primary cells have more internal resistance than the secondary cells.*

The internal resistance of a cell depends upon the following factors.

(1) The electrolyte :—Different electrolytes offer different resistances.

(2) Size of the plates :—The larger is the size of the plates the lesser is the resistance offered and *vice versa.*

(3) The nearness of the Plates—The nearer are the two plates in the cells, lesser is the resistance offered and *vice versa.*

(4) Strength of current :—As the strength of the current drawn from a cell is increased, its internal resistance, in general decreases.

19 **Secondard cells** :—The e. m. f. developed in the primary cells is due to the chemical reactions taking place in their electrolytes. These chemical reactions are *irreversible.* After the production of the current the products of the reaction are wasted and cannot be transformed into original substances But, there are other types of cells also in which the reactions are reversible and the products are not wasted. They are called *secondary cells or accumulators.*

When a current is made to pass through them, electrolysis takes place. Electrical energy is converted into chemical energy and is stored up in the cell. When the cell is connected to an external circuit, *i. e.*, when a current is drawn from it, the chemical energy is convered back into electrical energy. *The original substances are again obtained. Thus, the difference between a primary cell and a secondary cell is that in the primary cell chemical energy is converted into electrical energy direct, while in secondary cells electrical energy is first stored up in the cell as chemical energy, and this chemical energy is then converted into electrical energy.* As the current is obtained by secondary reactions, they are called secondary cells. They are also called accumulators or storage cells as charge is accumulated or stored in the form of chemical energy. The process of converting electrical energy into chemical energy is known as *charging the cell,* while the process of getting back the electrical energy from chemical energy is *known as discharging it.*

There are two types of secondary cel's : (1) *Acid accumulators.*

(1) Acid accumulator :— It consists of a glass ves containing dilute sulphuric acid. Two lead plates as shown in fig. 22 are dipped in the solution. The plates are constructed in the *form of grids or net works as shown in fig. 23, in the interstices of which is filled litharage* (PbO). PbO acts with H_2SO_4 to from $PbSO_4$. Thus, to start with both the plates contain a mixture of PbO and $PbSO_4$. The density of the acid is between 1'17 to 1'19.

Fig. 22

Charging :—Current is passed in the cell from an exter source, say, from D. C. mains or dynamo or bettery charger. D to this, hydrolysis of water ta place. Hydrogen is evolved the cathode while oxygen trav towards anode. The reactic are as follows :—

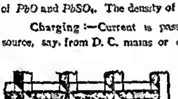

Fig. 23.

At the positive plate :—

$PbO + O = PbO_2$ ... (1)

$PbSO_4 + O + H_2O = PbO_2 + H_2S$

...

At the negative plate :—

$PbO + H_2 = Pb + H_2O$ ...

$PbSO_4 + H_2 = Pb + H_2SO_4$

...

By charging, positive plate is converted into dark bro peroxide of lead, while the negative plate becomes spongy le According to reactions (3) and (4) the amount of sulphuric a increases in the solution; hence its density increases because H_2SO denser than water. When it is completely charged, the density is n about 1'25 to 1'28. Its e. m. f. is near about 2'2 volts.

Discharging :—Current can be obtained from such a cell, w it has been charged. When current is drawn in the external circuit, flows from anode to cathode in the outer circuit, and just in reverse direction in the cell. Again the hydrolysis takes place. But, the direction of the current has reversed, hydrogen is evolved anode and oxygen at the cathode according to the fo equations :

At the positive plate :—

$$PbO_2 + H_2 = PbO + H_2O \qquad ...(5)$$

$$PbO + H_2SO_4 = PbSO_4 + H_2O \qquad ...(6)$$

At the negative plate :—

$$Pb + O = PbO \qquad ...(7)$$

$$PbO + H_2SO_4 = PbSO_4 + H_2O \qquad ...(8)$$

The reactions are self explanatory. When the cell is discharged, the original products PbO and $PbSO_4$ are again obtained. Water is formed during discharge, lowering the density of sulphuric acid. It again reaches the initial value of 1'17 to 1'19. Thus, *the cell regains its initial condition, and can be recharged. To know about its electrical condition the specific gravity of the acid should be occasionally measured by a hydrometer.*

The e. m. f. of such a cell remains almost constant at *about 2 volts.* When its *e. m. f. falls* suddenly to 1'8 volt, it is considered as having discharged fully. Use of battery having e. m. f. less than 1'8 volts is forbidden.

Notes :—(1) *It should not be charged by passing a heavy current* ; otherwise the plates get damaged and the material *peals off falling upon the base.*

(2) *When it discharges, its e. m. f. becomes near about 1'8 volts* and *specific gravity equal to 1'17.* No current should be taken *from this cell after this stage ; otherwise insoluble lead sulphates are formed greatly affecting the efficiency of the cell.*

(3) *The capacity of the cell is expressed in ampere-hours.* This shows the total amount of current which can be drawn *from* such a cell when it is fully charged If the capacity is 40 ampere hours, it can give a current of 40 amperes for one hour, or a current of 10 amperes for four hours etc. Greater is the size of the plates and greater is their number, greater is its capacity and rate of discharge.

(4) Its terminals *should never be short circuited ; otherwise* heavy current passes through it damaging the plates. This is due to its internal resistance being very low.

Generally, to increase its capacity instead of two plates a number of plates are taken. The plates are arranged in parallel alternately connected to the *two electrodes. By putting them in parallel their*

Advantages:— The accumulator possesses the following advantages over that of a primary cell :—

(1) It has got a number of plates which posses large area, and are placed very close to each other. This arrangement extremely reduces the internal resistance of the cell which is of the order of 0·0001 to 0·001 ohm. As it has got a high e. m. f. and low internal resistance, heavy and steady currents can be obtained from such a cell. This is not possible in the case of a primary cell which has very high internal resistance.

(2) As the reactions are reversible, it can be recharged.

(3) It can be used for lighting buildings, operating cars, etc. where strong currents are needed.

Despite all these advantages, it has got a few disadvantages also. It is very heavy and therefore, cannot be transported easily. Its cost is quite appreciable in comparison to a primary cell. Apart from this, it requires very careful handling. If it is not properly charged at the proper time, it will be rendered useless.

(ii) **Alkali accumulator (Edison cell):**— It consists of a steel plated container containing 20% solution of potassium hydroxide which constitutes the electrolyte. The positive plate is made up of nickel plated perforated steel tubes filled with nickel hydroxide mixed with finely divided nickel. The negative plate is also in the form of perforated iron tubes filled with iron oxide containing finely divide iron. Thus, the +ve plate is of nickel while -ve plate is that of iron, and hence it is called NI FE cell.

Charging :—Current is passed in the cell from an external source so that it passes from the nickel oxide plate to the iron oxide plate with in the cell. The reactions are as follows :—

At the positive plate :—

$2Ni(OH)_2 + 2(OH)^- = 2Ni(OH)_3 + 2$ —ve elementary charges.

At the negative plate :—

$Fe(OH)_2 + 2K^+ = Fe + 2KOH + 2$ elementary +ve charges.

Thus, during charging positive plate is converted in to $Ni(OH)_3$, while the negative plate is reduced to iron.

Discharaging :—During discharge, the current flows in the cell in the reverse direction given by the following reactions :—

At the positive plate :—

$2\,Ni\,(OH)_3 + 2K^+ = 2Ni\,(OH)_2 + 2KOH + 2$ elementary + ve charges.

At the negative plate :—

$Fe + 2OH^- = Fe\,(OH)_2 + 2$ elementary —ve charges.

The cell can be recharged after discharge. It is clear from the reactions that the concentration of KOH remains the same during charge and discharge. *When fully charged its e. m. f. is about 1.35 volts*

Advantages :—1. It has got great mechanical strength, and is less sensitive to mechanical vibrations. *As the tubes are quite strong,* there is no danger of buckling of the plates. Hence it possesses longer life.

2. It can be rapidly charged or discharged, without any damage to the plates. It can even withstand short circuiting and reverse charging. Hence, it requires very little attention and care.

3. For the same capacity it is only half as heavy as the lead accumulator.

4. Even when left idle for a longer time its e. m. f. remains constant.

Despite all these advantages, its cost is very *high.* It is costlier than a lead accumulater. Its efficiency is also quite low compared to lead accumulater, and its e. m. f. continuously falls during discharge.

Charging of an accumulator :—(a) Where D. C. (Direct current) supply is available, connect the accumulator to be charged to D.C. mains with a variable *high resistance* in series. High resistance can be obtained by employing an electric bulb. The current from the mains should enter the cell from the *+ve terminal. The current in the cell is* adjusted to the desired strength with the help of the variable high resistance. It is very important to see that the current flowing through the cell is kept at a value *specified by the manufacturers. Usually it is* written on the cell it self, as to at which strength of the current it is to be charged. When a lead accumulator is fully charged the density of the acid becomes 1·25 gm. per c.c. which can be tested with the help of

a hydrometer. When the alkali accumulator is fully charged its e.m.f. becomes 1·35 volts.

(b) When the supply available at a particular place is A. C. (Alternating current) as generally is the case, first of all the potential difference at which the current is supplied is lowered with the help of a step-down transformer. The current is then rectified by a rectifier so that it becomes unidirectional i.e. D. C. This unidirectional current is then used to charge the accumulators in the same way as described above. Generally rectifiers are available in the market which supply current either at 12 volts or 6 volts. potential difference. A rheostat is provided in the instrument it self to adjust the current to any desired value.

Oral questions :—Keys'—1. What is the use of keys ? 2. Explain the use of a commutator.

Galvanometers :—Explain the principle of a moving coil galvanometer, 4. Is the magnet used permanent or an electro magnet ? 5. Why the pole pieces are made. cylindrical. and an iron core is placed at the centre of the coil ? 6. What is difference between a suspended coil type and pivoted coil type galvanometer ? 7. Which type is more sensitive and why ? 8. Why the coil is deflected when the current is passed through it ? 9. Explain when the galvanometer is said to be dead beat type ? how is it secured in practice, and why is it made dead beat ?

Ammeters. and voltmeters:—10. What do you understand by a shunt ? 11. Distinguish between a galvanometer, an ammeter and a voltmeter. 12. Why an ammeter has low resistance while a voltmeter has high resistance ? 13. How these two are connected in the circuit and why ? 14. Why should the current enter in these instruments only from the positive terminal ? 15. How can you change the range of these instruments ? 16. What is a milli-ammeter and a milli-voltmeter ? 17. Can you measure A. C. current or A. C. voltage with these instruments ? If not, why ? 18. Describe a hot wire ammeter and a hot wire voltmeter ? 19. Can you measure D. C. current with a hot wire ammeter ? 20. How can an A. C. instrument be distinguished from that of a D. C. instrument ?

Rheostats and Resistance boxes:—21. Why the resistance wire used for their construction is usually of manganin ? Can you take copper

instead of manganin, if not why ? 22. *Why the wire is doubly wound ?* 23. Which alloy is superior for the construction of a resistance wire and why ? 24. What do you understand by specific resistance of a material ? 25. *Give the construction of a resistance box and a variable resistance (i. e. a rheostat). Which is more costly and why ? 26. How are the different resistances arranged in a resistance box ?* 27. What is the use of infinity plug ? 28. Why the coils in the rheostat are insulated from one another ? 29. Explain the meaning of 20Ω, 2 amp. written on the instrument ?

Primary cells :—30. *Explain the principle of primary cells,* and describe Daniell cell and Leclanche cell. 31. What *do* you understand by the e.m.f. of a cell, and explain how is it generated ? 32. Should the cells be *freshly prepared white starting the experiment ?* 33. What are the *defects of these cells* and *how are they eliminated ? 34. Describe* a standard cell. 35. Can these cells be employed to obtain a constant supply of current ?

Secondary cells :—31. Explain the principle of a secondary cell? 32. How does it differ from a primary cell ? 33. Why is it called an accumulator ? 34. What *types of accumulators* are generally employed in the laboratory ? 35. What is the *difference* between an acid accumulator and an alkali accumulator ? 36. Compare and contrast the two types of accumulators ? 37. *What is internal resistance of a cell and how* has it been minimised in case of an accumulator. 38. What do you understand by the capacity of an accumulator ? 39. What do you mean by 40 amp. at two hours rate ? 40. How is *their capacity increased ?* 41. *How are they* charged again ? 42. When should they be put *for recharging* and why ? 43. What are their demerits ? 43. Give reactions taking place in both the types of accumulators while charging and *discharging ?* 44. Explain the functions of a rectifier ? 45. Why these cells are charged at a constant current ? 46. Why should not they be short circuited ?

Name of cell.	Kind of electrolyte	Positive Plate	Negative Plate	Depolariser	E.M.F. in volts	Internal Resistance	Remarks.
1. Leclanche cell	Ammonium chloride solution.	Carbon	Zinc	MnO_2 powder	1·5	Upto 5 ohms.	MnO_2 being solid, it is not able to oxidise H_2 readily and hence polorisation sets in. It, therefore does not give steady current and is used intermittently.
2. Daniell cell	Dil. H_2SO_4 Soln.	Copper	Zinc	$CuSO_4$ Soln.	1·1	Up to 5 ohms.	It gives very steady e.m.f. and whenever battery is not available, it can be used for steady current.
3 Bichromate cell	Dil. H_2SO_4 Soln	Carbon	Zinc	$K_2Cr_2O_7$	2.2	low.	Gives strong current due to low internal resistance.
4. Bunsen cell	Dil. H_2SO_4 Soln.	Carbon	Zinc	HNO_3	2	,,	Gives fumes which are harmful. They are not very common.
5. Acid accumultator	Dil H_2SO_4 Soln	PbO_2	Spongy lead	—	2.2	0·1 ohm.	These are available with two or greater no. of odd plates. Greater the number and greater the area, greater is its capacity and lower is internal resistance
6. Alkali.	Dil. KOH Soln.	Ni_2O_3	Fe	—	1·35	0·1 ohm	It is not advisable to draw very heavy current from 5th but this can be used for such purposes.

Note:—No. 5 and 6 are secondary cells and are also called accumulators. If their e m f. goes below 1.8 or 1.2 respectively, they should not be used but first recharged. They are costly and hence, their use is recommended only when steady current is needed.

EXPERIMENT No. 17

Experiment: To compare two nearly equal resistances with the help of a potentiometer.

Apparatus: A potentiometer, a four way key, a galvanometer, a [illegible] two resistances which are to be compared, two secondary cells, two rheostats, two plug keys, connecting wires etc.

Description of the apparatus:—Potentiometers are of various forms. The simplest type which is commonly employed in most of the laboratories is ten wire type. You are already quite familiar with that potentiometer.

The use of so many wires makes the apparatus cumbersome. Moreover, it is also difficult to obtain such a long wire of absolutely uniform cross section throughout its entire length. Therefore these difficulties have been surmounted by connecting a comparatively short wire in series with a number of resistance coils as shown in fig. 1

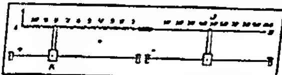

Fig. 1

The resistance of each coil is equal to the resistance of the wire. Normally ten such coils are taken, and put in series with a wire (generally of 50 cm. length), upon which slides the jockey J. J is connected to the —ve terminal of the secondary circuit. K is a contact maker, which slides over the studs of the coils. K is connected to the +ve terminal of the secondary circuit (see fig. 2). By this arrangement any number of coils can be taken in the circuit for comparison purposes, hence the length of the potentiometer wire can be altered. The slide wire is generally divided into 100 equal divisions. The length of each coil is taken to be equal to 100 divisions. (Suppose

the contact maker K is lying on coil no. 7, and J is at 25th divis
then the balancing length will be $=7\times100+25=725$ divisions.)

Theory:—For both the cases the potentiometer wire can
regarded as a single wire as shown in fig. 2. The connections
self explanatory.

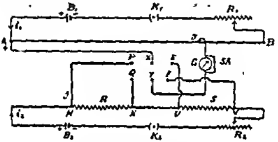

Fig. 2

Suppose R and S are the two resistances to be compared.
i_1 and i_2 be the steady current flowing respectively through the pote
meter wire AB, and the two resistances R and S. Let V_1 and V_2
respectively the potential difference across R and S. Now if l_1 is
balancing length of the potentiometer wire (*when there is no cur
in the galvanometer*), when the *p. d.* V_1 across R is balanced
it, we have.

$V_1=R\,i_2=l_1\,x$ ... ... (i), where x is the potential grad
along the wire AB.

Similarly let l_2 be the balancing length of the potentiometer
when *p. d.* V_2 across S is balanced on it, we have.

$$V_2=S\,i_2=l_2\,x \text{ ... ...(ii)}$$

By dividing (i) by (ii) we get.

$$R/S=l_1/l_2 \text{ ... ...(iii)}$$

Method:—1. Make neat and tight connections as shown
fig. (2). To start with, connect the +ve terminal of the batter
to the end A, while the –ve terminal to the end B through
rheostat R_1 and Key K_1. This constitutes the primary circuit. Jo
end A to the terminal X of a four way key. Connect Y to jocke

through the galvanometer G. This can be done by conn the terminal Y to either of the terminals C or D of brass strip (see fig. 3) Shunt the galvanometer.

Fig. 3.

2. Connect the two resistances R and S and the rheostat R_2 in series with a battery B_2 through a key K_2. This constitutes the secondary circuit.

3. Connect the higher potential terminals M and U of R and to the terminals P and E respectively, and lower potential termin N and V to the terminal Q and F respectively.

4. Close K_2. Adjust R_2 so that a small potential difference is s up across R and S. Now join P to X and Q to Y. Close K_1 and bring th jockey near one end A of the wire and press. Note the direction of deflectio in the galvanometer. Remove the jockey to other end and repeat th procedure. If the deflection in the galvanometer is *in the opposit direction, connections are correct* so far R is concerned. Determine the approximate value of the balancing lenght l_1 corresponding to the *p. d.* accross R. Now disconnect P from X; and Q from Y, and join X to E and Y to F and repeat the above procedure, if the deflection in the galvanometer becomes *opposite* as before, connections are correct for S also. Similarly determine the approximate value of the balancing length l_2 corresponding to the *p. d.* across S. It $l_1 > l_2$; R>S or vice versa. If the deflection in the galvanometer is one sided in either case, the coooections are wrong and test for the following.

(i) The higher potential terminals M and U of R and S should be conoected to the terminals P and E of the key.

(ii) V_1 and V_2 are not individually less than the p.d. across the potentiometer wire. It is an essential condition for obtaining null point that V_1 and V_2 should be less than the p.d. across the potentiometer wire. To secure this either increase R_2 or decrease R_1.

(iii) If still the deflection remains one sided test whether battery B_1 is fully charged or not.

5. Now connect the terminals X and Y to the two ends of the resisance R or S which ever is higher (which may be known from step

4). Adjust the rheostat R_1 so that the balance point is obtained near about the end B i. e. balancing length becomes large. This adjustment increases the *sensitiveness of the potentiometer, and at the same time the p. d. between A and B remains more than V_1 or V_2 which are to be compared.*

To determine l_1 :—6. Connect P to X and Q to Y, so that p.d. across R is balanced on the potentiometer wire. Slide the jockey and obtain a null point when there is no deflection in the galvanometer. For the final adjustment remove the shunt from the galvanometer. Measure the length of the wire from the end A to this point. This gives l_1, the balancing length corresponding to the p.d. across R.

To determine l_2 :—7. Disconnect P from X and Q from Y, and join X to E and Y to F and repeat the above procedure (now p.d. across S is being compared). Similarly obtain the new balancing length l_2 corresponding to the p.d. V_2 across S. It is extremely important that during taking one set of readings for l_1 and l_2, the current i_1 and i_2 should remain constant in the two circuits. This will be one set.

8. Change R_1 and R_2 (decrease R_2 or increase R_1), and again take another set. In this way take at least five or six different sets for l_1 and l_2.

9. Determine the ratio $\frac{l_1}{l_2}$ from each set. Then determine the mean ratio $\frac{l_1}{l_2}$.

Observations:—

S. N.	Length corresponding to the p.d. across R (l_1) in cms.	Length corresponding to the p.d. across S (l_2) in cms.	$\frac{l_1}{l_2}$	Mean $\frac{l_1}{l_2}$
1				
......				
6				

Calculations :—Calculate $\frac{l_1}{l_2}$ by each set and then determine mean $\frac{l_1}{l_2}$.

Result:—*The ratio between the two resistances* R and S $= \frac{R}{S} =$

Precautions and sources of error:—1. The most important point to be borne in mind in this experiment is that p.d. between the *two ends A and B of the potentiometer* wire should always remain greater than the potential difference V_1 or V_2 across R or S; If this condition is not satistied, deflection in the galvanometer will be only one sided.

2. R_1 should be adjusted for the maximum sensitiveness of the potentiometer.

3. Do not forget to put a shunt across the galvanometer It *should be removed only near the null point.*

4. The resistances R or S should not be disturbed or mishandled during the experiment while comparing V_1 and V_2.

5. Currents should be passed in the two circuits only when taking readings, otherwise heating will start altering the values of R and S.

6. Jockey should be pressed against the wire only for a small time. Do not slide the Jockey with contact on. It causes the deformation of the wire.

7. All the higher potential terminals should be connected at one point, i. e. A and of the wire.

Criticism:—This method is quite satisfactory. The slight error present is due to the non-uniformity of the potentiometer wire and the inconsistancy of the e.m.f.s of the two batteries employed. This method is specially suited for the comparison of two nearly equal low resistances. For greater accuracy Crompton's potentiometer should be used.

Modifications:—*1. To determine an unknown resistance with the help of a potentiometer.*

Hints.—By the above process determine the ratio $\frac{R}{S}$. *If R is known S can be determined. For this purpose R is taken in the form of a resistance box. Care should be taken to choose such a resistance from the resistance box that l_1 and l_2 are comparable. This is necessary in order to eliminate the* [illegible] *to non-uniformity of the wire.*

However, if the unknown resistance S is very low, the following method should be employed.

2. **To determine a low resistance by potentiometer.**

Hints.—1. Make neat and tight connections as shown in figure 4. R is a resistance box and S is the unknown resistance. Make primary and secondary circuits as described above.

2. Take a two way key with terminals X Y Z. Connect the higher potential terminal M of R. B. to the higher potential end A of the potentiometer wire.

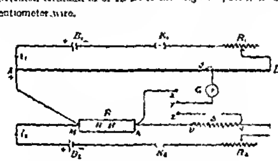

Fig. 4

The lower potential terminals N and N of R and S are respectively connected to X and Z. Connect Y to J through the galvanometer G.

3. Connect X to Y so that p.d. across R. B. is compared) and determine the balancing length l_1 corresponding to the p.d. V_1 across R in R. B.

4. Disconnect X from Y and join Y to Z. (Now p.d. across R and S is being compared). Similarly determine the new balancing length l_2 corresponding to the p.d. V_2 across the series combination formed by the two resistances R and S. The currents in the two circuits should be kept constant during these operations.

5. By changing the values of R in the resistance box, obtain more sets for the lengths l_1 and l_2.

6. Calculate S by each set from the following formula.

7. If i_1 is the current flowing through the resistances R and S and x is the potential gradient along AB, we have

$$V_1 = l_1 x = i_1 R$$

Similarly, $V_2 = l_2 x = i_1 (R + S)$

$$\therefore \quad \frac{R+S}{R}=\frac{l_2}{l_1}$$

or $\quad S=\left(\frac{l_2}{l_1}-1\right)R.$ when R is known, S can be calculated knowing l_1 and l_2.

8. Determine the mean value of S It will come out to be in ohms.

Oral Questions :—1. Describe a potentiometer giving its principle of working. 2. What is the use of a potentiometer? How many types of potentiometers you know, and which is the best? 3. What is potential gradient ? 4. How can you increase or decrease the potential gradient ? 5. Is it possible to employ primary cells in the primary and the secondary circuits, if no, why ? 6. Why is it necessary that the same current should flow through both of the resistances which are being compared ? 7. What should be the order of the resistances you are comparing ? 8. Why should they be nearly equal ? 9. Is this method suitabe for comparing high resistances ? 10. How will you determine low reristance by this method ? 11. Why is it essential that the potential difference across the two resistances must be separately less than the potential difference across fhe potentiometer wire ? 12. What do you understand by null point in this method ? 13. Explain when there will be no current in the galvanometer ? 14. When is the potentiometer most sensitive ? 15. Why the wire of the potentiometer must be of uniform cross-section ? 16. Can you determine the specific resistance of a wire by potentiometer, if yes, how ?

EXPERIMENT No. 18

Experiment – To calibrate a voltmeter with the help of a potentiometer.

Apparatus :—A potentiometer, two accumulators, two rheostats, a galvanometer, a voltmeter, shunt, two way key, one way keys, connecting wires etc.

Description of the apparatus :—See experiment no 17.

Theory :—The connections are self explanatory (see fig. 1). In this experiment, the same potential difference is simultaneously measured with the help of a potentiometer and the given voltmeter. Hence the error in the reading of the instrument is determined. To obtain this, the potential gradient along the wire is found out with the help of a standard cell. If the standard cell is not available which is generally the case, Daniell cell can be employed in its place, and its e.m.f. may be taken as 1·07 volts.

Let l_1 be the balancing length of the potentiometer wire, when the e.m.f. E of a Daniell cell is balanced on it. Then, we have,

$E = l_1 x$ (where x is the potential gradient along the potentiometer wire).

$$\therefore \quad x = \frac{E}{l_1} \text{ .... (i)}$$

Let l_2 be the balancing length of the wire when potential difference V_1 across the portion MW of the rheostat is balanced on it. Then, we have,

$$V_1 = x l_2 \text{ .... (ii)}$$

From eqns. (i) and (ii) we have,

$$V_1 = E \frac{l_2}{l_1} \text{ .... (iii)}$$

Let the reading in the voltmeter for the same potential difference across the portion MW of the rheostat be V_2. Then the error in the reading of the instrument will be $= V_1 - V_2$. As the contact W is variable the voltmeter can be calibrated for its full range. A graph is then

drawn between the actual readings of the voltmeter and the corresponding errors.

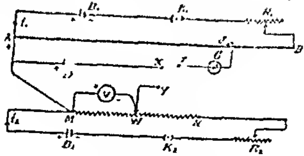

Fig. 1

Method —1. Make neat and tight connections as shown in fig. 1. Connect the end A of the potentiometer wire to the + ve terminal of the battery B_1, and the end B to the —ve terminal of the battery through the reheostat R_1 and key K_1. Evidently the potential of the point A is higher than that of B It constitutes the primary circuit

2. Connect the fixed terminal M of the rheostat to the + ve terminal of the battery B_2, and the other fixed terminal N to the —ve terminal of the battery through a key K_2. Evidently the potential of the terminal M is higher than that of N i.e. M is a higher potential terminal. It consitutes the secondary circuit.

3. Join the +ve pole of Daniell cell to the end A, and the - ve pole to the tetminal X of a two way key.

4. Connect the higher potential terminal M of the rheostat to the end A, and the variable terminal W to the terminals Y of the key.

5. Join the middle terminal Z to the jockey J through a galvanometer G. Put a shunt across the galvanometer.

6. Connect the higher potential terminal M and variable terminal W of the rheostat respectively to the + ve and —ve terminals of the given voltmeter.

7. Close the key K_2 and by adjusting R_2 and the rheostat MN, obtain full scale deflection in the voltmeter. Now close K_1. If the full scale deflection in the voltmeter is more than the e. m. f. of Daniell cell, connect Z to Y i. e. the sliding contact W to the jockey J through the galvanometer. If the full scale deflection is less than the e. m. f. of Daniell cell, connect X to Z i. e. - ve pole of the cell to the jockey through the galvanometer. Now try to obtain the approximate balance point *as nearer to the end B as possible.*

This *ensures maximum sensitivity of the instrument and* at the *same time the potential differenc between the two ends A and B* *remains more than the potential difference which is to be comp*ared. If the deflection remains one sided and null point is not obtainab... the wire A B, *follow the following procedure* :

(a) Either reduce the resistance in R_1, so that the current i... primary circuit increases, increasing *p. d.* between the ends A and...

(b) Or increase the number of accumulators in the pr... circuit so that *p. d.* between the ends A and B increases.

Remember that *p. d.* between A and B should always r... more than the *p. d.* which is to be measured.

Suppose the maximum range of the given voltmeter is ... volts. Then 1000 cm. of potentiometer wire should balance aga... *p. d.* of 3 volts. Hence for 1 volt the length of the wire shou... approximately 1000/3=330 cm. say. So while calibratin... potentiometer wire with the help of a Daniell cell, see tha... balancing length is near about 330 *cm*.

To determine l_1 :—

8. Connect X and Z and adjust the jockey J, so that ... is no deflection in the galvanometer. Determine this bal... length l_1 of the potentiometer wire corresponding to the e. ... E of Daniell cell. This gives l_1. Thus, the potentio... wire is calibrated. Remove the shunt while making final adjustm...

To determine l_2 :—

9. Disconnect X from Z, and join Y to Z. close K_2 ... by sliding the contact W, so adjust that the voltmeter ... 0.1 or 0.2 volt. Now determine the balancing length l_2 of... potentiometer wire corresponding to the p. d. across the portion ... of the rheostat. Evidently you are balancing the potentiometer... corresponding to the p. d which is also being measured directly b... voltmeter.

10. Note down the reading in the voltmeter. Let it ... Calculate the true value V_2 for the same p. d. with the he... formula (iii), and determine the error. V_1-V_2.

11. By sliding W change the p. d. across the terminals M and W. W should be so moved that the reading in the voltmeter may increase in steps of O. 1 or O. 2 volt. Again for each reading in the voltmeter determine the balancing length. and calculate the corresponding error. Follow this procedure till the deflection in voltmeter is full scale.

12. Draw a grapn between the observed readings of the voltmeter and the corresponding errors.

Note :—Some times it is better to take a fixed resistance R in place of the rheostat MN, as shown in fig. 2. The voltmeter is put across the two terminals of the fixed resistance.

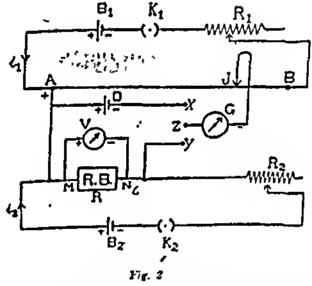

Fig. 2

In this case the p. d. across R is varied by adjusting the rheostat R_2. The rest of the procedure is the same. This method is better because while changing p. d. the fluctuations are less, and hence null point is not disturbed.

Observations :—

Observation table for l_1 and l_2.

S.N.	Balancing length corresponding to the e. m. f. of cell (l_1) in cm.	Balancing lengt corresponding to the p. d. across the portion MW of the rheostat or the resitance box (l_2) in cm.	Actual p.d $V_2=E\frac{l_2}{l_1}$ in volts	Obsered p.d. in voltmeter V_1 in volts	Error V_1-V_2 in volts
1					
2					
⋮					
⋮					
10					

Note :—The readings for the balancing length l_1 should be taken twice or thrice during the experiment to ensure, whether it remains the same or not.

Calculations —Calculate V_2 in each case *from fo.mula iii)*

$$x=\frac{E}{l_1}= \text{..... ....volt/cm.}$$

$$V_2=xl_2=E\frac{l_2}{l_1}\text{. ....volts.}$$

Result :—The graph between the observed readings and the corresponding errors will be as shown in fig. 3. It is called the calibration curve for the voltmeter.

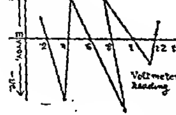

Fig. 3

precautions and sources of error :—1. All the higher potential terminals should be connected to the end A of the potentiometer wire.

2. The storage batteries used must be fully charged and possess large capacities, so that their e.m. fs. may remain constant during the performance of the experiment.

3. The potential difference across the two ends A and B of the

11. By sliding W change the p. d. across the terminals M and W. W should be so moved that the reading in the voltmeter may increase in steps of O. 1 or O. 2 volt. Again for each reading in the voltmeter determine the balancing length, and calculate the corresponding error. Follow this procedure till the deflection in voltmeter is full scale.

12. Draw a graph between the observed readings of the voltmeter and the corresponding errors.

Note :—Some times it is better to take a fixed resistance R in place of the rheostat MN, as shown in fig. 2. The voltmeter is put across the two terminals of the fixed resistance.

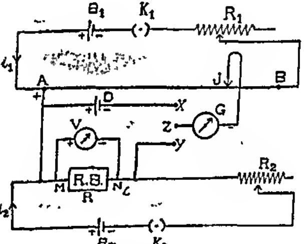

Fig. 2

In this case the p. d. across R is varied by adjusting the rheostat R_2. The rest of the procedure is the same. This method is better because while changing p. d. the fluctuations are less, and hence null point is not disturbed.

Observations :—

[1]. E. M. F. of the Daniell cell (E) = 1 0? volts.

Observation table for l_1 and l_2.

S.N.	Balancing length corresponding to the e. m. f. of cell (l_1) in cm.	Balancing length corresponding to the p. d. across the portion MW of the rheostat or the resitance box (l_2) in cm.	Actual p.d $V_2=E\frac{l_2}{l_1}$ in volts	Obsered p.d. in voltmeter V_1 in volts	Error V_1-V_2 in volts
1					
2					
⋮					
⋮					
10					

Note :—The readings for the balancing length l_1 should be taken twice or thrice during the experiment to ensure, whether it remains the same or not.

Calculations —Calculate V_2 in each case from formula (ii)

$$x=\frac{E}{l_1}=\text{..... ....volt/cm.}$$

$$V_2=xl_2=E\frac{l_2}{l_1}\text{ ....volts.}$$

Result :—The graph between the observed readings and the corresponding errors will be as shown in fig. 3. It is called the calibration curve for the voltmeter.

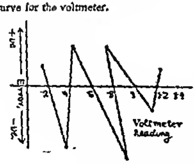

Fig. 3

precautions and sources of error :—1. All the higher potential terminals should be connected to the end A of the potentiometer wire.

2. The storage batteries used must be fully charged and possess large capacities, so that their e.m. fs. may remain constant during the performance of the experiment.

3. The potential difference across the two ends A and B of the

11. By sliding W change the p.d. across the terminals M and W. W should be so moved that the reading in the voltmeter may increase in steps of 0.1 or 0.2 volt. Again for each reading in the voltmeter determine the balancing length and calculate the corresponding error. Follow this procedure till the deflection in voltmeter is full scale.

12. Draw a graph between the observed readings of the voltmeter and the corresponding errors.

Note :—Some times it is better to take a fixed resistance R in place of the rheostat MW as shown in fig. 2. The voltmeter is put across the two terminals of the fixed resistance.

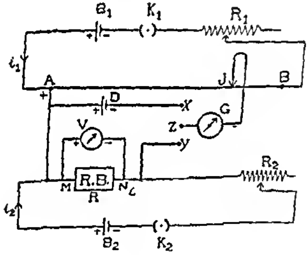

Fig. 2

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point is not disturb

Observations :—

[1]. E. M. F. of t

Observation table for l_1 and l_2.

S.N.	Balancing length corresponding to the e. m. f. of cell (l_1) in cm.	Balancing length corresponding to the p. d. across the portion MW of the sheostat or the resitance box (l_2) in cm.	Actual p.d. $V_2 = E\frac{l_2}{l_1}$ in volts	Obsered p.d. in voltmeter V_1 in volts	Error $V_1 - V_2$ in volts
1					
2					
⋮					
⋮					
10					

Note :—The readings for the balancing length l_1 should be taken twice or thrice during the experiment to ensure, whether it remains the same or not.

Calculations—Calculate V_2 in each case from formula (ii)

$$x = \frac{E}{l_1} = \ldots\ldots\ldots\ldots \text{volt/cm.}$$

$$V_2 = xl_2 = E\frac{l_2}{l_1} \quad \ldots\ldots\ldots \text{volts.}$$

Result :—The graph between the observed readings and corresponding errors will be as shown in fig. 3. It is called the calibrati curve for the voltmeter.

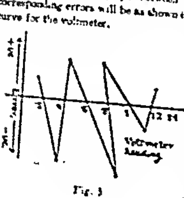

Fig. 3

precautions and source of errors:—1. All the higher potential terminals should be connected to the end A of the potentiometer wire.

2. The storage batteries used must be fully charged and possess large capacities, so that their e.m.f. may remain constant during the performance of the experiment.

3. The potential difference across the two ends A and B of the

the percentage accuracy depends upon ... good results. Howev
gradient. The potential gradient depends upon the constancy of the potenti
wire as well as the constancy of the e.m.fs of the batteries used. For
accurate calibration, the exact e.m.f of the Daniell cell should be
substituted. Daniell cell should be freshly prepared when starting the
experiment.

Oral questions — 1. See experiment no. 17. 2. What do you
understand by calibration of a voltmeter and how is it done? 3. How
the wire of the potentiometer is calibrated? 4. Why it is necessary to calibrate the potentiometer wire? 5. Why a standard cell
cell serve this purpose? 6. When is the potentiometer most sensitive
of a given range if a voltmeter to be calibrated? 7. Can you use a
resistance box instead of a rheostat in the secondary circuit?

EXPERIMENT No. 19

Experiment :—To calibrate an ammeter with the help of a potentiometer

Apparatus :—A potentiometer, two accumulators, two rheostats, galvanometer, a standard one ohm resistance coil, the ammeter which is to be colibrated, shunt, two way key, Two one way keys, connecting wires etc.

Description of the apparatus :—See experiment No. 17.

Theory :—The connections are self axplanatory (see fig. 1). In this experiment the same current is simultaneously measured with the help of a potentiometer and the given ammeter. Hence the error in the given instrument is determined.

Let l_1 be the balancing length of the potentiometer wire when the E. M. F. E of a Daniell cell is balanced on it. Then we have,

$E = l_1 x$ [where x is the potential gradient along the potentiometer wire].

$\therefore \quad x = E/l_1 \; \ldots \; \ldots \; \ldots (i)$

Let l_2 be the balancing length of the potentiometer wire when P. D. V_2 across the two ends of a standard resistance R is balanced on it. Then we have,

$V_2 = x l_2 \; \ldots \; \ldots \; \ldots (ii)$

From (1) and (2) we have,

$$V_2 = E\frac{l_2}{l_1} \quad \ldots \quad \ldots \quad \ldots (iii)$$

If i_2 is the current flowing in the standard resistance R and the mmeter,

$$i_2 = \frac{V_2}{R} \quad \ldots \quad \ldots \quad \ldots \quad \ldots (iv)$$ If the standard sistance is a one ohm coil.

$i_2 = V_2 \; \ldots \; \ldots \; \ldots \; \ldots (v).$

Substituting the value of V_2 from eqn. (3) in eqn. (5) we get,

$$i_2 = E\,\frac{l_2}{l_1} \quad \ldots \quad \ldots \quad \ldots (vi)$$

[illegible] ... ater
[illegible] ... d of t
[illegible] ... ary [illegible]

[illegible] series [illegible] the battery [illegible] key K_1. It constitues the [illegible]

3. Connect the +ve pole of the Daniell cell to the end A and the −ve pole to the terminal X of two way key.

4. Join the higher potential terminal of the one ohm coil to the end A, and the lower potential terminal to the terminal Z of the two way key

5 Join the middle terminal Y to the jockey J through a galvanometer G. Put a shunt across the galvanometer.

6 Close K_1 and by adjusting R_1 obtain full scale deflection in the ammeter. If corresponding to this full scale deflection, the potential difference between the two ends of the one ohm coil is greater than the e.m.f. of the Daniell cell, connect Z to Y, i.e the lower potential terminal of the one ohm coil to the jockey On the other hand if for the full scale deflection the potential difference is less than the e.m.f. of the Daniell

Calculations –

Calculations from relation (1) ...

$I_2 = I \frac{l_2}{l_1}$ amp

$\therefore$ error ... amp

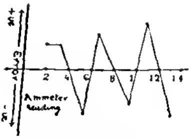

Fig.

Result ... been ... the corresponding ... as ... the ... ammeter

Note ... with ammeter. The ... page

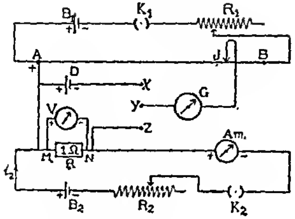

Fig. 3

Precautions and sources of error —

1. Same as in the previous experiment.

2. The ammeter should be connected in the secondary circuit in such a way that the current in it should always enter from the positive terminal.

3. All the wires connecting the higher potential terminals should be led towards the higher potential terminal of the potentiometer wire.

Criticism.—See previous experiment. The percentage accuracy as described before depends upon the following factors. (i) The constancy of the battery e.m.f. (ii) accurate knowledge of the e.m.f. of the Daniell cell (iii) uniformity of the potentiometer wire. (iv) accurate knowledge of the value of the standard resistance (v) and constancy of the potential gradient. For greater accuracy instead of an ordinary one ohm coil, standard resistance coil should be taken.

Oral questions :—

1. See experiment no. 17 and 18. 2. What do you understand by the calibration of an ammeter and how is it done ? 3. Why a standard one ohm coil is preferred in the secondary circuit, can you use any value of the resistance ? 4. Is the calibration of the potentiometer wire done accurately with the help of a Daniell cell ? 5. Can you suggest any better cell for calibration purpose ? 6. Do you know any other method of calibrating an ammeter ? Which of the methods is superior and why ? 7. Can you calibrate voltmeter and ammeter simultaneously ? If yes, how ?

In this particular case the two resistances P and Q are supplied by the resistances X and Y respectively connected between the gaps AB and BC (see fig 2). The jockey D divides the

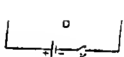

Fig. 1

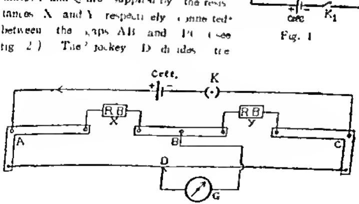

Fig. 2

bridge wire in two parts. These two parts supply the resistances R and S. Let the balance point on the bridge wire (indicated by

no current in the galvanometer) lie at a distance l_1 cm. from the end A which is connected to the resistance X. Then, the resistances R and S would be respectively proportional to the lengths l_1 and $(100-l_1)$ cm. of the bridge wire. Hence relation (i) will become.

$$\frac{X}{Y}=\frac{l_1}{(100-l_1)} \quad \dots \quad \dots \quad \dots \quad (ii)$$

Often the soldering of the wire with the brass strips is defective. The solder spreads at the ends forming an alloy with the bridge wire. As the specific resistance of this alloy is different from that of the bridge wire, the resistance of the wire at the two ends changes from its initial value. Furthermore, the two ends of the wire may not exactly coincide with the 0 and 100 cm. divisions of the scale i.e. the scale may be slightly disturbed. Due to this error the length of the wire as read on the scale may be slightly more or less than the actual value, depending upon the position of the zero. Moreover, the brass strips also possess some resistance. All these factors introduce *certain extra resistances at the two ends*, which are known as *end corrections*. Where accuracy is to be obtained these end corrections are not too small to be neglected.

Let these end resistances at the left and the right end be respectively equal to the resistance of α and β cm length of the bridge wire. Then, the corrected length of the two segments of the wire would be $l_1+\alpha$ and $100-l_1+\beta$. Therefore, equation (ii) becomes,

$$\frac{X}{Y}=\frac{l_1+\alpha}{100-l_1+\beta} \quad \dots \quad \dots \quad \dots (iii)$$

Let the resistances X and Y be interchanged. If the new balance point lies at a distance of l_2 cm. from the left end A which is now connected to the resistance Y, we have,

$$\frac{Y}{X}=\frac{l_2+\alpha}{100-l_2+\beta} \quad \dots \quad \dots \quad \dots (iv)$$

Solving (iii) and (iv) we get

$$\alpha=\frac{Yl_1-Xl_2}{X-Y} \quad \dots \quad \dots \quad \dots (v)$$

and $$\beta=\frac{Xl_1-Yl_2}{X-Y} \quad \dots \quad \dots \quad \dots (vi)$$

Knowing X, Y, l_1, and l_2, α and β can be determined.

[illegible]

To determine

6. After [illegible] balance point [illegible] indicated by no deflection [illegible] and determine the [illegible] distance of the null point from [illegible] l_1 twice and then find out mean l

Note.—The null point will be near [illegible] the bridge wire

To determine l_2 —

7. Now interchange the two resistances X and Y [illegible] left gap the resistance is—10 ohm while in the right gap [illegible] As described above again determine the balance point [illegible] distance of this new balance point again from the left end A [illegible] gives l_2. Similarly determine l_2 twice and then find out mean l_2

Note.—In this case the null point will be at the other end of the wire

8. Keeping the value of X = 1 ohm, change the value of Y 20 ohm and determine the corresponding lengths l_1 and l_2. y take atleast two to three sets for l_1 and l_2.

9. Calculate α and β from each set, and then determine the r each α and β.

Observations :—

N.	Resistance		Distance of the balance point from the left end A with X in the						α in cm.
	X in ohm.	Y in ohm.	Left gap (l_1) in cm.			Right gap (l_2) in cm.			
			I	II	Mean	I	II	Mean	
1									
2									
3									

Calculations:—Determine α from the formula,

$$\alpha = \frac{Yl_1 - Xl_2}{X - Y}, \text{ and}$$

$$\beta = \frac{Xl_1 - Yl_2}{X - Y} - 100 \text{ for each set,}$$

and then determine the mean for each α and β.

Result—(1) End correction for the left end = ...cm
(2) End correction for the right end = ...cm

Note.—The end corrections are determined in terms of the length bridge wire. If they are to be determined in ohms the α and β should be multiplied by the resistance per unit le the bridge wire.

Precautions and sources of error :—

1. Current should be passed in the circuit, only whe observations. It will prevent unnecessary heating of the re coils, and hence the value of their resistances will not change.

2. To start with galvanometer must be properly otherwise it will be damaged.

3. The jockey should not be moved with contact on, o the uniformity of the cross-section of the wire will be destroyed.

Questions [illegible]

[illegible] uniform [illegible] When [illegible] determined by the end [illegible] existence? [illegible] Are [illegible] the conditions [illegible] 11. Explain [illegible] end corrections are determined. [illegible] 13. What ratios of X and Y [illegible] the most accurate [illegible] end corrections. 14. Which key should be pressed first and why?

EXPERIMENT No. 21

Experiment :—To calibrate the Careyfoster's bridge wire (i. e. to determine resistance per unit length of the wire), and then to determine difference between two nearly equal resistances.

Apparatus :—A Careyfoster's bridge, Leclanche cell, galvanometer, rheostats, two coils each of one ohm resistance, resistance box, fractional resistance box, copper strips, the two resistances which are to be compared, key, shunt wire, connecting wires etc.

Description of the apparatus :—It is the modified form of a metre bridge. A *Careyfoster's bridge*, consists of a metre long wire of uniform cross section stretched along a wooden board. The wire is made of an alloy of high specific resistance and low temperature coefficient (of ureka or manganin), and runs parallel to a metre scale also fixed on the board The ends of the wire are soldered to two thick brass strips. Theoritically speaking the two ends should coincide respectively with 0 and 100 cm. divisions marked on the scale. Three brass strips running parallel to the wire are fixed on the board between

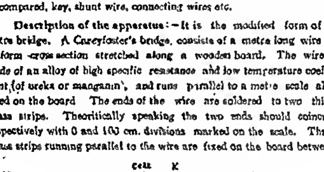

Fig. 1

the two brass strips soldered at the two ends. These five strips of brass constitute four gaps as shown in fig. 1. Terminals with binding screws are provided on all these strips. The two resistances X and Y *which are to be compared are connected in the outer gaps of the bridge. They are in series with the bridge wire.* The two nearly equal resistances P and Q are put in the inner gaps AB and BC (generally they are one ohm coils)... Rest of the connections are self explanatory.

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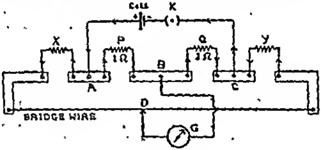

Fig. 1

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mined. It is known as the calibration of the bridge wire. To calibrate the bridge wire a fractional resistance box is put in the left outer gap, and a thick copper strip is put across the right outer gap. Thus, Y is reduced to zero. Let the resistance in the resistance box be R (i.e. X=R) Now let the balance point be situated at a distance l_1' from the left end which is connected to the resistance R. After interchanging R and the copper strip let the new balancing length from the left end (which is now joined to the copper strip) be l_2'. Then, from relation (v), we get.

$$R=\rho\ (l_2'-l_1') \quad \cdots \quad \cdots \quad \cdots \quad \cdots \quad \cdots \quad \cdots \text{(vi)}$$

$$\text{or} \qquad \rho=\frac{R}{(l_2'-l_1')} \cdots \quad \cdots \quad \cdots \quad \cdots \quad \cdots \quad \cdots \quad \cdots \text{(vii)}$$

Method.—To determine ρ i. e. to calibrate the bridge wire:—

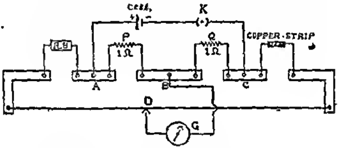


Fig. 2

1. Make neat and tight connections as shown in fig. 2. The connections should be done by thick copper wires so that the resistances in the four arms of the bridge remain the same.

2. Connect a fractional resistance box in the left outer gap. Short circuit the right outer gap by connecting a thick copper strip across its ends. In each of the inner gaps connect a standard one ohm coil (so that P=Q=1 ohm).

3. Connect a Lochanche cell to the terminals A and C through a key.

4. Connect one terminal of the galvanometer G to the terminal B (terminal lying on the middle strip), and the other to the jockey D. Shunt the galvanometer.

To determine l_1' :—

5. Introduce a resistance = 0·1 ohm in the fractional resistance box. Put the plug in the key, and determine the approximate balance

11. Interchange X and Y in the outer gaps and similarly determine l_2.

12. Take at least three sets for l_1 and l_2. Knowing ϱ, l_1 and l_2 determine the diffrence between X and Y from each set, and then determine the mean difference.

Note:—When P=Q, it is not possible to take more sets for l_1 and l_2, because these values will allways remain almost the same. To surmount this difficulty, as described earlier, a rheostat is used instead of two resistances P and Q. The connections are as shown in fig. 3, The two fixed terminals of the rheostat

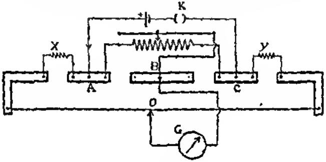


Fig. 3

are connected to the terminals A and C. The variable terminal is connected to the terminal B. Hence the resistance of the rheostat is divided in to two parts supplying the two ratio arms P and Q. In this case for the same values of X and Y a number of different sets for l_1 and l_2 can be taken by varying the resistances in the two parts of the rheostat. Hence it is preferable.

Observations:—

[1] *Table for the determination of* (ϱ), *the resistance per unit length of the wire*:—

S. N.	Resistance in R. B. (R) in ohms	Distance of the balance point from the left end when R is in the: Left gap (l_1') in cm.			Right gap (l_2') in cm.			$(l_2'-l_1')$ in cm.	$\varrho = \frac{R}{l_2'-l_1'}$	Mean ϱ ohm/cm.
		I	II	Mean	I	II	Mean			
1										
2										
3										

11. Interchange X and Y in the outer gaps and similarly determine l_2.

12. Take at least three sets for l_1 and l_2. Knowing ρ, l_1 and l_2 determine the diffrence between X and Y from each set, and then determine the mean difference.

Note—When P=Q, it is not possible to take more sets for l_1 and l_2, because these values will allways remain almost the same. To surmount this difficulty, as described earlier, a rheostat is used instead of two resistances P and Q. The connections are as shown in fig. 3. The two fixed terminals of the rheostat

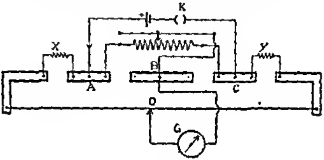


Fig. 3

are connected to the terminals A and C. The variable terminal is connected to the terminal B. Hence the resistance of the rheostat is divided in to two parts supplying the two ratio arms P and Q. In this case for the same values of X and Y a number of different sets for l_1 and l_2 can be taken by varying the resistance in the two parts of the rheostat. Hence it is preferable.

Observations—

[1] *Table for the determination of* (ρ), *the resistance per unit length of the wire*—

S. N.	Resistance in R. B. (R) in ohms	Distance of the balance point from the left end when R is in the Left gap (l_1') in cm.			Right gap (l_2') in cm.			$(l_2'-l_1')$ in cm.	$\rho = \frac{R}{l_2'-l_1'}$	Mean ρ ohm/cm.
		I	II	Mean	I	II	Mean			
1										
2										
......										
3										

resistances $(X-Y) = \ldots$ ohms.

Precautions and sources of error :—1. All the connectio should be tightly done. Fractional resistance box and the other resis tance coils (which are generally small) should be connected in th respective gaps with thick copper wires, so that the connecting wire may not have their own extra resistances.

2. Allow the current to *flow* through the circuit only when ta king observations, *otherwise unnecessary heating of the resistances will* take place altering their values.

3. *Jockey* should not be moved on the wire with the contact on, otherwise the wire well get disfigured, and the cross-section will not remain uniform.

4. First, allow the current to flow through the cell circuit and ... galvanometer circuit. Do the reverse of it while switching

5. While calibrating the bridge wire, the resistance in the fractional resistance box should be adjusted to obtain the two null points *as near the ends as possible.* This makes (l_2-l_1) very nearly equal to the entire length of the bridge wire and the error due to the non uniformity of the wire is reduced to minimum.

6. As Described earlier, it is preferable to use a rheostat to obtain the two ratio arms P and Q. Of course, for greater sensitivity of the bridge the sliding contact on the rheostat *should be adjusted to render P and Q almost equal. It is not* at all necessary to know the values of P and Q. When P=Q and the wire is of uniform cross-section, the two null points obtained before and after interchanging the resistances in the outer gaps will be situated at equal distances from the centre of the wire. If P is much different from Q, it would not be possible to get the null point on the bridge, therefore, there should not be much difference between the values of P and Q. By using a rheostat the null point can be obtained on any part of the wire, Hence, more number of sets can be taken for a given set of values for X and Y. This is not possible when fixed resistance coils are connected in the inner gaps.

7. The difference between the two resistances X and Y should not in any case be greater than the *resistance of the bridge wire,* otherwise it would not be possible to obtain the null points.

8. While determining the *difference* between X and Y, the null point should be obtained as near to the centre of the wire as possible. This reduces the error in determining the position of the null point to the minimum and hence sensitivity will be increased.

9. See experiment No. 23.

Modifications—1. *To determine an unknown resistance with the help of a Careyfoster's bridge.*

Hints—1. Determine the resistance per unit length of the wire (ρ) as described above.

2. Put the unknown resistance in the left outer gap in place of X, and a resistance box in the right outer gap in place of Y. Similarly find out the two balancing length l_1 and l_2 and calculate X by the formula

$$X = \rho(l_2 - l_1) + Y.$$

As Y and ρ are known X can be determined.

2. To determine the end corrections of the Carey Foster's bridge wire :—

Hints — Close the two outer gaps [illegible] [illegible] [illegible] the [illegible] to [illegible] the end corrections. [illegible] closing two gaps the bridge takes up [illegible] a metre bridge.

Criticism — This is a much better method of comparing two nearly equal resistances. Theoretically, the sensitivity of the metre bridge is directly proportional to the length of the wire which cannot be increased beyond limits. In this case, however, by providing two extra resistances in the outer gaps, the length of the wire has been virtually increased. Hence it is very sensitive and the accuracy attained is quite high in comparison to a metre bridge. As is evident from the formula *by interchanging* the two resistances the end corrections are totally eliminated. Hence the result obtained is quite accurate. However, the non-uniformity in the cross-section of the wire and the slight heating produced in the resistance coils impairs the accuracy of the result obtained. The following treatment will very much help in understanding about the *sensitivity of the bridge.*

Suppose in an experiment on metre bridge the balancing length of the wire is l corresponding to an unknown resistance X, then we have

$$X = \frac{l}{L-l} R,$$ where L is the total length of the wire and R is the known resistance in the other gap. If dx is the small error produced in determining X due to a small error dl produced in finding the length l, then the percentage inaccuracy $\frac{dx}{X}$ is given by,

$$\frac{dx}{X} = \frac{L\,dl}{l(L-l)} = \frac{dl}{l(1-l/L)}$$

Now $\frac{dx}{X}$ is minimum when $l = \frac{L}{2}$ therefore, the minimum value for $\frac{dx}{X}$ would be given by,

$$\frac{dx}{X} = \frac{4}{l}\,dl.$$

For a metre bridge $dl = 1$ mm, and L $= 100$ cm.

$$\therefore \frac{dx}{X} = \frac{4}{100} \times \frac{1}{10} = \frac{1}{250}.$$

Hence, the *percentage accuracy* is directly proportional to the length of the wire L. Therefore, to enhance the percentage accuracy

gth should be increased which is actually done in Careyfoster's arrangement.

n the balanced state of the bridge. if dl is the small shift in the ›int on account of a small charge dR in the known resistance R, ·e,

$$R=\frac{L-l}{l}X$$

or $$dR=-\frac{LX}{l^2}\cdot dl$$

$$\therefore \quad \frac{dl}{dR}=-\frac{l^2}{LX}$$

As l is a fraction of L, $l=n$L, where n is less than one. Hence,

$\frac{dl}{dR}=-\frac{n^2}{X}L$; therefore, sensitiveness of the bridge is also ·tional to the length of the wire. Thus, Careyfoster's bridge is not ·ccurate, it is sensitive also than the other arrangements.

questions:—

1. Explain the principle and working of a Careyfoster's bridge. hat are its advantages over that of a metre bridge ? 3. What do nderstand by the sensitiveness and accuracy of a Careyfoster's bridge? hat factors do these two depend ? 4. How do you find out the ance per unit length of the wire? 5. Why a deciohm box is employed d of an ordinary resistance box while calibrating the wire ? What type of resistances should be connected in the two inner gaps ? t should be their values ? 7. Can you connect a rehostat instead of wo resistances ? 8. Which is the better arrangement and why ? hould the two resistances in the inner gaps be exactly equal ? How can you compare two resistances by a Careyfoster's bridge ? What should be the order of these resistances. 12. What is the mum permissible difference between the two resistances ? 13. Is it ble to compare the two resistances even without calibrating the ? 14. Why we do not consider end corrections in this experiment ? How can you test for the uniformity of the wire ? 16. Why thick er strip is employed to short circuit the gap ? 17. See the previous iment.

EXPERIMENT No 23

Experiment — *To determine the value of J, the mechanical equivalent of heat by an electrical method using a Joule's calorimeter.*

Apparatus — Joule's calorimeter, accumulators, a voltmeter, ammeter, a rheostat, stop watch, a thermometer preferably reading to $\frac{1}{5}$ °C, weight box, physical balance connecting wires etc.

Description of the apparatus — *Joule's Calorimeter* — It consists of a thin copper vessel C of about half a litre capacity. It is provided with an ebonite lid. Two thick copper leads are suspended in the vessel through the ebonite cover. The upper ends of the leads are provided with binding screws fixed on the surface of the lid as shown in fig. 1. The two ends of a heating coil are soldered to the two lower ends of the leads. For making a heating coil, high resistance wire (generally made of eureka or manganin) is used. There is a hole at the centre of the lid. A thermometer T is inserted through this hole so that its bulb remains dipping in water contained in the calorimeter.

A stirrer S is inserted in the calorimeter through another hole provided at the edge *of the cover. The calorimeter* is put in a wooden box containing a layer of felt or saw dust, to prevent heat losses due to radiation. Water is filled in the calorimeter so that the coil remains immersed in it. *Rest of the connections* are self explanatory. Current through the coil is measured with the help of the ammeter, where as the p. d. across its ends is given by the voltmeter.

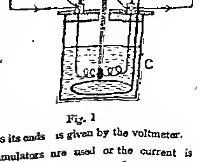


Fig. 1

In laboratories where accumulators are used or the current is derived from a D. C. supply ordinary voltmeter and ammeter is

employed as shown in fig. 1. In some laboratories where the current is obtained from an A. C. source, first of all a step down transformer is used to lower the potential difference of the supply to about 6 to 8 volts. This p. d. is then used to pass current through the heating coil. A rheostat is used to regulate the current in the circuit. In this

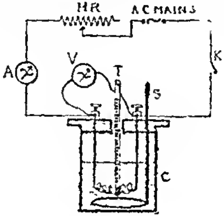


Fig. 2

case an A. C. voltmeter and an A. C. ammeter is used, as shown in in fig. 2.

Theory :—Let E be the potential difference across the two ends of the heating coil in volts and I be the current passing through it in amperes. If the current is passed for an interval of t seconds, the work done W, by the current in ergs is given by the relation,

$$W = EIt \times 10^7 \ldots\ldots\ldots\ldots (1)$$

So much amount of energy will be converted in to heat which will be absorbed by the calorimeter and its contents. Then, by Joule's law we have,

$$J = \frac{W}{H} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where J is the mechanical equivalent of heat, and H is the amount of heat produced.

$$H = (W_1 + m)\ (t_2 - t_1) \ldots\ldots (3)$$

Where W_1 is the water equivalent of the calorimeter and the stirrer, m is the mass of water in the calorimeter, t_1 is the initial temperature of water, and t_2 is the final corrected temperature of water.

From (i) and (iii) we get,

$$J = \frac{EIt}{(W_1 + m)(\theta_2 - \theta_1)} \times 10^7 \text{.......................(iv)}$$

and $W_1 = m_1 S_1$ ....(v)

Where S_1 and m_1 are respectively the specific heat and mass of calorimeter including stirrer.

Method :—1. *Take the Joule's calorimeter* and clean it. Determine the mass of the calorimeter and stirrer with the help of a physical balance. *It gives m_1.*

2. Fill two thrids of the calorimeter with water which may be sufficient to immerse *the heating coil. Again determine its mass with the help if a physical balance.* Let it be m_2 gm. Determine the difference between these two masses i. e. between m_2 and m_1. It gives m, the mass of water *contained in the calorimeter.*

3. *Put the heating coil* in the calorimeter so that it *remains* fully immersed in water. Now close the lid and put the calorimeter in the wooden box.

4. Now make neat and tight connections as shown in fig. 1. *Connect the resistance coil (heater), the ammeter* A, *the rheostat, and a* key K in series with a battery of accumulators (three to four accumulators should be used in series). Current in ammeter must enter from the +ve terminal. Connect the voltmeter V across the two terminals of the *heating coil. +ve of the voltmeter should be connected to that terminal* of the leads, through which the current enters the heating coil. *If* current is to be derived from D. C. mains a high resistance should be *included* in the circuit. *(If A. C. is to be used* connections are to be made as shown in *fig. 2. Feed A. C. in to a step down transformer* from the mains, and connect an A. C. ammeter, a suitable rheostat and a key in series with the ont put terminals of the step down transformer, *hich has not been shown in the diagram.* In this case put an A. C. oltmeter across *the two terminals of the heating coil.]*

5. Put the plug in the key, and adjust the current in the calorieter. The p. d. *across the heating coil* should preferably be adjusted etween 6 to 8 volts with the *help of a rheostat. Now determine the* emperature of water with the help of the *thermometer T and imme*ately start the stop-watch. Due to the flow of current in the coil, *eat will be produced. Consequently* the temperature of water will rise. ir the water constantly *with the help of a stirrer.*

6. Find out the current passing through the coil with the help of the ammeter. It gives I. Determine p. d. across the two ends of the heater with the help of the voltmeter. It gives E. If the p. d. varies during the performance of the experiment keep it constant by adjusting the rheostat.

7. When the temperature of water rises by nearly 8 to 10° C, stop the current and immediately determine the time for which the current has been passed with the help of a stop-watch. It gives t. When the current is switched off, immediately determine the temperature of water by the thermometer. Let it be θ_2°C.

To determine radiation correction :—To obtain this correction, allow the water to cool for the same time, for which it was heated. Determine the fall in temperature of water during this time. Let it θ_4°C., then the radiation correction will be $\frac{\theta_4}{2}$°C. Add this value to θ_2 to get the final corrected temperature θ_3.

9. If possible, change the current in the calorimeter and similarly obtain another set of readings for all the quantities. If time permits, two to three such different sets should be taken.

10. Determine J from each set, and then find out the mean value of J.

[*Note.*—Some times a copper voltameter is also employed to measure current in the coil].

Observations :—

1. Mass of the calorimeter with stirrer (m_1) =... ... gm.
2. Mass of calorimeter with stirrer + water (m_2) =... ... gm.
3. Initial temperature of water (θ_1) =... ... °C.
4. Final temperature of water (θ_2) =... ... °C.
5. Current passing in the heating coil (I) =... ...amp.
6. Potential difference across the heating coil (E) =... ... volts.
7. Time for which the current was passed (t) =... ... sec.
8. Fall in temperature of water after cooling for the same time for which the current was passed (θ_4) = ...°C.
9. Sp. heat of copper (S_1) = ...

Calculations :—

1. Mass of water (m) = ($m_2 - m_1$) = ...gm.
2. Final corrected temperature (θ_3) $=\left(\theta_2+\frac{\theta_4}{2}\right)=$ ....°C.

3. Water equivalent $(W_1) = m_1 S_1 = ...$ ... gm.

Substitute the values of E, I, t, m, θ_2, θ_1 and W_1 in equati

$$J = \frac{E\,I\,t}{(W_1 + m\,(\theta_2 - \theta_1)}$$, and calculate the value of J.

Result:—The mechanical equivalent of heat = ...ergs per

Precautions and sources of error :—1 It is very importa this experiment to check up the connecti ns before starting the cu If the instruments are not properly connected, they may be damage

2. The potential diffrence across the heating coil should n any case exceed 6 to 8 volts, otherwise electrolysis of water producing serious errors.

3. The water should be stirred canstantly so that the temper through out the calorimeter may remain uniform. It should als stirred while determining the radiation correction.

4. The radiation correction should always be applied.

5. The current should be kept constant through out the operat of the experiment. It can be achieved with the help of a rheostat.

6. The final temperature of calorimeter and its contents m not be allowed to increase by more than 10°C over that of the ro temperature, otherwise heat losses due to radiation will be quite large

7. If possible, thermometer reading up to $\frac{1}{10}$°C should *employed to register the temperatures.*

Criticism :—The value of J determined by this method is n *very accurate due to the following reasons.*

(i) Though the radiation correction is applied, radiation loss cannot be completely eliminated. Therefore, the amount of hea *calculated is always less than the amount of heat generated. Thus, th* value of J obtained by this method is slightly higher.

(ii) As the thermometer and the heating coil also posses thermal capacity, they also take up some heat which is extremely difficult to account for.

(iii) *Some heat is also lost due to the evaporation of water.*

(iv) The current flowing through the voltmeter is also not negligible and hence the actual current flowing through heating [illegible]

(v) Due to rise in temperature, the resistance of the heating coil varies, and it becomes very difficult to keep the current and the p. d. across it constant through out the experiment.

To obtain better results, the heating coil should be made of the material possessing very high specific resistance and negligible temperature coefficient. The voltmeter should possess high resistance, and liquid possessing low vapour pressure should be used instead of water. To minimise the radiation losses colorimeter must be placed in a double walled chamber in which water flows constantly.

Oral Questions —1 What is Joule's law ? 2 Define J, and explain how is it determined in this method ? 3. Explain how the work is done and heat is produced in this experiment ? 4. Where is the heating coil placed in this experiment ? 5. Why thick copper leads are taken ? what will be the harm if the wire is directly connected to the terminals. ? 6. What is the material used in the construction of the resistance wire used in the heater and why ? 7. What is radiation correction and how is it applied. 8. Why the p. d. across the heater should not be increased beyond 8 volts ? 9. Why this method is not very accurate ? 10. How much rise in temperature is permissible in this experiment ? 11. Do you know any other better elctrical method for determining J ?

EXPERIMENT No. 23

Experiment—To determine the value of J, the mechanical equivalent of heat by Callender's and Barne's continuous flow calorimeter.

Apparatus—A constant level bath. Callender and Barne's continuous flow calorimeter, an ammeter, a voltmeter, a rheostat, a beaker, a stop watch, battery of accumulators, two thermometers reading upto $\frac{1}{5}$ °C, measuring flask, weight box, physical balance, key and connecting wires etc.

***Description of the apparatus:-Callender and Barne's continuous flow calorimeter*—It consists of a heating coil made of fine nichrome** wire, mounted along the axis of a narrow glass tube as shown in fig. I. The two ends of the heating coil are soldered to two terminals provided on narrow metal tubes attached to the ends of the glass tube. Two wider metal tubes are attached to these narrow metal tubes with small

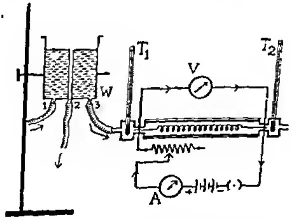


Fig. I

pieces of rubber tubbings. The wider tubes are provided with side tubes which serve as inlet and outlet for the water flowing in the calorimeter. Water enters the calorimeter from the left side and leaves by

the right side tube. The wider tubes are fitted with corks at the top. Holes are drilled in the corks, and two thermometers T_1 and T_2 are inserted in them. T_1 gives the temperature of water entering the calorimeter, while T_2 the temperature of water flowing out of the calorimeter.

W is a constant level water bath. Its outlet tube is connected to the inlet tube of the calorimeter. Rest of the connections are self-explanatory. Current is passed in the heating coil either from a battery of accumulators (see fig. 1 or from an A. C. source as described in the last experiment.

Theory:—Let I_1 (in amp.) be the current flowing through the coil when E_1 (in volts) is the potential difference across its two ends. Then, the amount of work done W (in ergs) by the current in one sec. is given by the relation,

$$W = EI \times 10^7 \text{.........................} (i)$$

Due to this, heat is produced in the coil. If J is the mechanical equivalent of heat, and H the amount of heat produced per sec. in calories, we have,

$$J = \frac{W}{H} \text{.........................} (ii)$$

Major portion of this heat is absorbed by the current of water continuously flowing through the calorimeter while a small part of it is lost to the surroundings due to radiation. *In the steady state, (i. e. when the temperatures of the inflowing and outflowing water attain steady values)*, let the amount of heat absorbed by the current of water in one second be H_1 calories, and that lost in one second due to radiation etc. be H_2 calories. Then we have,

$$H = H_1 + H_2$$
$$= m_1 S\,(\theta_2 - \theta_1) + H_2 \text{..........} (iii)$$

Where m_1 is the mass of water flowing out per sec., S the sp. heat of water, θ_1 θ_2 the temperatures of the inflowing and out flowing water respectively. From eqns. (i), (ii) and (iii) we get,

$$E_1 I_1 \times 10^7 = J\,[m_1 S\,(\theta_2 - \theta_1) + H_2] \text{.....} (iv)$$

Let the current flowing in the heater be now changed to I_2, and let E_2 be the new potential difference across its two ends. The rate of flow of water is now so adjusted that in the steady state the difference in temperatures registered by the two thermometers T_1 and T_2 is again

the same i. e. $(\theta_2-\theta_1)$. Thus the heat lost per sec. due to radiati both the cases in the same. If now m_2 is the mass of water flowing per sec., we have,

$$E_2I_2\times10^7=J\{m_2(\theta_2-\theta_1)S+H_2\}......(v)$$

Eliminating H_2 from eqns. (v) and (iv), we get,

$$J=\frac{E_1I_1-E_2I_2}{S(m_1-m_2)(\theta_2-\theta_1)}.$$ If S is taken to be equal to u we get,

$$J=\frac{E_1I_1-E_2I_2}{(m_1-m_2)(\theta_2-\theta_1)}..........(vi)$$

Method.—1. Make the *connections* as *shown in fig. 1.* Conn the *heating coil*, the *ammeter*, the *rheostat* and the key in series with battery of accumulators. [*If* A. C. current is to be used, follow t procedure described in the previous experiment i.e. the heating coil shou be placed in series with the out put termtoals of a stepdown transfo mer]. Connect the voltmeter across the two ends of the heating coi Current in both of these instruments should enter from the +ve terminals

2. Connect the inlet tube of the constant level bath W to a wate tap, and its out let tube to the inlet tube of the continuous flow calori meter with the help of a rubber tubing. (The central tube of the constant level bath is connected to the sink). Adjust the flow of water from the tap so that the level of water in the bath remains constant (surplus water is discharged in the sink through the central tube). Adjust the height of the water bath so that a slow but steady and continuous current of water issues out of the outlet tube of the calori- meter. (The water should come out nearly at the rate of 1 to 2 c. c. per minute).

3. Now switch on the current, and with the help of the rheostat adjust its value to near about 1·5 to 2 amp. Due to the passage of current heat will be produced in the coil. The heat so produced will be taken up continuously, by the stream of water flowing in the glass tube. Consequently the temperature of the out flowing water will gradually rise indicated by the thermometer T_2.

4. *By adjusting the height of the water bath*, adjust the *rate of flow of water so that a temperature difference* of about 4 to 5°C *is set* up between the two *thermometers* T_1 and T_2. *Now wait till the tem- peratures in the two thermometers attain steady values.* To know whether they have attained steady values or not, read the two thermr

meters after every five minutes. If there is no change in the respective values of temperature denoted by them for nearly three consecutive readings the temperatures may be considered to be steady.

5. After obtaining the steady conditions and noting that the rise in temperature is near about 4 to 5°C, read the two thermometers T_1 and T_2. They will respectively give θ_1 and θ_2.

6. To determine the mass of water flowing out per sec., take a clean and perfectly dry measuring cylinder. Put the cylinder below the the outlet tube of the calorimeter and simultaneously start the stop-watch. Collect water for a certain interval of time say, for t_1 seconds. (Generally the water is collected for 10 to 15 minutes). After t_1 seconds, immediately remove the cylinder and stop the stop-watch. Determine the volume of water collected in t_1 sec. from the measuring cylinder. As the density of water is unity, numerically the volume will be equal to the mass of water collected in t_1 sec. Let it be M_1 gm. From this observation, determine the mass of water m_1 flowing out per sec.

Note:—It can also be found out by taking a weighed beaker and collecting water in it for t_1 sec. The beaker is again weighed. The difference between to two masses gives the water collected in t_1 sec.

7. Determine the value of the current I_1 flowing through the coil with the help of ammeter A.

8. Measure the potential difference (E_1) across the two ends of the conductor with the help of voltmeter V. It constitutes one set of observations.

9. Now slightly alter the value of the heating current. By lowering or raising the constant level bath, adjust the flow of water in such a way that again in steady conditions same temperature difference ($\theta_2 - \theta_1$) is established between the two thermometers. It is very important to see that the rise in temperature ($\theta_2 - \theta_1$) is exactly the same in both the sets of observations.

10. Find out the value of the current (I_2) flowing in the coil by the ammeter and p. d. (E_2) across it by the voltmeter.

11. As described in step 6, determine the changed rate of flow of water (m_2) i. e. the mass of water flowing out per sec. Again take two to three different observations for the determination of m_2. It constitutes second set of observations.

12. If there is time, more sets of readings should be taken by altering current and adjusting rate of flow of water (keeping the rise in temperature same).

13. Now switch off the current and disconnect the inlet tube of the calorimeter from the constant level tank.

14. Determine J by taking into consideration any two sets of observations (if you have taken more than two sets) and then find the mean value of J.

Observations :—

[1]. Temperature of the inflowing water (θ_1) = ... °C.
[2]. Temperature of the outflowing water (θ_2) = ... °C.

[3]. *Table for the first set of observations.*

S.N.	P.D. in Volts (E_1)	Current in amp. (I_1)	$E_1 \times I_1$	Mass of water collected in gm. (M_1)	Time taken in sec. (t_1)	Mass of water flowing out per sec. in gm. $m_1 = \frac{M_1}{t_1}$
1						
2						
3						

[4]. *Table for the second set:—*

S.N.	P.D. in volts (E_2)	Current in amp. (I_2)	$E_2 \times I_2$	Mass of water collected in gm. (M_2)	Time taken in sec. (t_2)	Mass of water flowing out per sec. in gm. $m_2 = M_2/t_2$
1						
2						
3						

[5]. Prepare similar tables, if you take more than two sets.

Calculations :—Knowing all the values required, calculate the value of J by the formula,

$$J = \frac{E_1 I_1 - E_2 I_2}{(m_1 - m_2)(\theta_2 - \theta_1)}$$

Use any of the two sets taken, for calculation purposes.

Precautions and sources of error :—1. The heating wire should be taken in the form of a spiral. This particular shape of the wire will keep the water *automatically stirred*, and at the same time large volume of water will come in contact with the heater.

2. The rate of flow of water through the glass tube should be kept constant, otherwise θ_1 and θ_2 will not remain steady. It can be done by properly adjusting the constant level bath.

3. Current in ammeter and voltmeter should enter from the terminal marked +ve.

4. The rate of flow of water, and the current should be so adjusted that the rise in temperature is near about 4 to 5°C.

5. As the rise in temperature is small it should be measured very accurately. Preferably thermometers reading up to 1/10°C should be used.

6. The rise in temperature ($\theta_2 - \theta_1$) should be exactly the same in the two sets of observations.

7. To start with, first let the water flow in the calorimeter and then switch on the current. Reverse this order at the end of the experiment. If it is not done so, due to excessive heat produced in the coil, there is a danger of its getting burnt.

Criticism :—The value of J obtained by this method is fairly accurate. Losses of heat due to *radiation* have been eliminated to a very great extent by taking two sets of observations for the same *rise of temperature*. Since, in these conditions the temperature at every point of the apparatus is the same in both the sets, heat losses are also the same. The greatest advantage of this method is that after the attainment of *steady state* there is no change in temperature on any part of the instrument, hence no further heat is absorbed by calorimeter, heater, or thermometers. *Thus no correction is needed for their thermal capacities.* As the two temperatures become steady, they can be determined with a high degree of accuracy. As the water is well stirred temperature over any cross-section of the tube remains uniform. To further reduce the heat losses due to radiation the glass tube should be enclosed by a hermetically sealed vacuum jacket.

Despite all these advantages the accuracy of the result is hampered by the errors present in the various measuring instruments e.g. ammeter, voltmeter, thermometers etc. The current measured is more than actually flowing in the heater, because a part of it also flows through the voltmeter.

EXPERIMENT No. 24

Experiment :—To determine the frequency of an electrically maintained tunning fork with the help of Melde's experiment.

Apparatus :—An electrically driven tunning fork, accumulator, thread, pulley, physical balance, weight box, metre scale, clamps etc.

Description of the apparatus :—One end of a long and light string (usually in the form of a thread) is tied to one of the prongs of a large tuning fork T (see *figs. 2* and *3.*) The other end of the thread passes over a pulley and carries a pan or a hanger in which weights can be placed. By changing the weights placed in the pan, tension can be altered in the string. The vibrations of the tuning fork are maintained electrically.

Electrically maintained tuning fork—T is a tuning fork clamped to a stand or on a table. An electro-magnet C is placed between its two prongs as shown in fig. 1. One terminal of the battery is connected to the shank of the tuning fork, while the other is connected to an adjustable screw S through the coil of the electro magnet C. The screw is provided with a platinum tip. One end of a metallic strip *p* is fixed to one of the prongs of the fork, while its other end is put in front of an adjustable screw *S*. When the screw is moved forward its tip touches the free end of the strip *p*, completing the electric circuit. Due to the flow of current in the coil, the electro-magnet is actuated, and the two prongs of the fork are attracted towards the electromagnet. Thus, the two prongs are pulled inwards. This results in breaking of the contact between the strip and the screw, and therefore, current stops to flow. The electro-magnet loses its magnetism and no longer keeps the prongs attracted. Hence, the prongs moves outwards, and again the contact between the strip and screw is established. Again, the current flows in the coil and the whole process

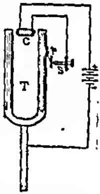


Fig. 1

is continually repeated tending to move the prongs forwards and backwards. Thus, due to the make and break of the current in the circuit the vibrations of the tuning fork are maintained.

Theory :—When the tension is properly adjusted, stationary waves are produced on the thread, and it splits up in to one or more number of vibrating loops. There are two modes of vibration of the fork with respect to the thread. Nodes are formed at places where the thread is fixed to the prong, and where it touches the pulley, irrespective of the mode of vibration.

[1] Transverse mode of vibration :—In this arrangement the prongs of the tuning fork vibrate in a plane prependicular to the length of the thread i. e. the thred is stretched in line with the length of the prong. (see fig. 2). In between the two nodes formed at the two ends, number of nodes and antinodes are formed depending upon the number of loops. Evidently therefore, the length of the thread between one loop (i. e. between two nodes) is equal to half the wave length of the waves formed on the thread. In this arrangement

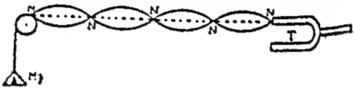


Fig. 2

the thread moves up and down with the prong of the tuning fork, and so during the period tuning fork completes one vibration thread also performs one vibration. Hence, the frequency of the vibrating thread is equal to the frequency of the tuning fork. If p is the number of loops formed, l the length of the thread containing these p loops and n the frequency with which the string is vibrating then we have

$$n = \frac{p}{2l}\sqrt{\frac{T}{m}} \qquad \ldots \qquad (1)$$

where T is the tension equal to [illegible] and m the mass per unit [illegible] frequency of the tuning fork [illegible]

[illegible]

the string i. e. the thread is stretched at right angles to the length of the prong. Between the two nodes formed at the ends number of nodes and antinodes are formed depending upon the number of loops.

In this arrangement, when the prong moves towards the extreme left position, a sag is produced in the thread in the downward direction. When the prong moves towards extreme right, the thread becomes straight and taut, acquiring velocity in the upward direction. When the prong again moves towards left, the thread instead of sagging moves

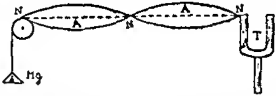


Fig. 3

upwards, on account of the velocity it possesses. Thus during the time tuning fork completes one vibration, the thread completes only half of the vibration. Hence the frequency of the thread is half that of the the fork.

As before, if p is the number of loops formed, l the length of the thread containing these p loops and n_1 the frequency of the thread, we have

$$n_1 = \frac{p}{2l}\sqrt{\frac{T}{m}} \text{ ....(iii)}$$

Where T and m are respectively the tension applied and mass per unit length of the string. As in this case, $N = 2n_1$, we have,

$$N = \frac{p}{l}\sqrt{\frac{T}{m}} \text{ ....(iv)}$$

N, the frequency of the tuning fork can be determined either from equation (ii) or (iv)

Note.—It is clear from these equations, that a string of length l, under a tension T will break up into double the number of loops in transverse arrangement than that in the longitudinal arrangement.

Method —[A] Transverse arrangement—1. Connect one terminal of the accumulator to the stalk of the tuning fork (see Fig. 1).

while the other to the adjustable screw S through the coil of the electro magnet C.

2. Take a long and light thread and *fix* one of its ends to the prong of an electrically driven tuning fork with the help of a binding screw provided on the prong. Pass the thread over a fractionless pulley and from its other *end suspend a pan. Put* the tuning fork as shown in fig. 2 so that its prong is in line with the thread.

3. Now move the adjustable screw so that it touches the tip and current begins to flow in the coil of the electro magnet. Due to the flow of current the fork begins to vibrate.

4. Put suitable amount of weights in the pan, so that the thread splits up in to several loops. By using smaller weights or sand, adjust the tension in such a way that the *loops become clear and well defined.* The nodes must reduce to fine points.

5. After this adjustment, select a certain number of well defined *loops (it is better to leave the first and the last loop). Count them. It* gives p.

6. Determine the length of the thread between the loops counted i. e. between p loops) with the help of a metre scale. It gives l. Measure l atleast twice and determine the mean value of l.

7. Find out the mass of the weights (including sand if put) laced on the pan. Let it be $=m_1$ gm. Now weigh the pan. Let its mass be $=m_2$ gm. The total amount of mass suspended M gm. s, $M=m_1+m_2$. Knowing M, determine the tension applied ($T=Mg$. *here g is the acceleration due to grairty).*

8. Take a certain length of the specimen thread. Determine its ngth (L) by a meter scale, its mass (M) by a balance, and then lculate its mass *per unit length (m).* Take atleast three different oservations.

9. Knowing l, p, T and m determine the frequency N by this set ing formula (ii).

10. To take more *sets of readings*, alter tension varying the ounts of weights placed in the pan. Number of loops will conse ently change. As described above, again adjust the amount of weights t in the pan to obtain clear and well defined loops. Again determine corresponding values *for l and p*. In this way by altering ten

take at least three different sets of observations, and switch off the current.

11. Calculate N by each set, and determine the mean value of N.

[B] **Longitudinal arrangement:**—12. In this case make connections as described in step 1, and place the tunning fork as shown in fig. 3. Now the thread is stretcted prependicular to the length of the prong.

13. As described above, adjust the tension and determine the correspondings values for p and l.

Note:—It would be observed that in this case for the same values of l, T, N and m, the number of loops is reduced to half.

14. Change tension by changing the amount of weights put in the pan, and similarly take three different observations for p and l. Find out the value of T in each case as described above.

15. Knowing the value of m, the mass per unit length of the string, calculate N by each set using formula (iv). Determine the mean of N.

16. Now determine the mean of the two values of frequency obtained from transverse and longitudinal arrangements.

Observations :—

[1] Acceleration due to gravity $g = \ldots$ cm /sec./sec.

[2] *For the determination of m.—*

S. N.	Mass of the thread (M_1) in gm.	Length of the thread (l_1) in cm.	Mass per unit length $m = \frac{M_1}{l_1}$ in gm.
1			
2			
3			

Oral Questions :—1. What type of waves are produced on string. ? How are they produced ? 2. Explain nodes and antinod 3. What is the difference between stationary waves and progress waves ? 4. What are the laws of vibration of a string ? 5 Wh are the two modes of vibration of the fork with respect to the thread 6. Describe the experimental arrangement in two modes. 7. Wh is the ratio of the frequency of the thread in the two modes ? 8. F the same values of N, l T, and m do you get the same number loops in the two modes, if not why ? 8. How can you change th number of loops obtained on the thread ? 9. If you are gettin seven loops in the transverse arrangement, how many loops would yo expect in the longitudinal arrangement ? Give reasons for you answer. 10. Can you verify the laws of transvers vibration of string by this method ? explain how the vibrations of the fork are maintained 12. Why a spark is produced at the point of contact, and how can th be reduced or eliminated ? 13. What are the sources of error in this experiment and how are they eliminated ?

EXPERIMENT No. 25

Experiment :—To find the focal length of a combination of two lenses separated by a certain distance by nodal slide method.

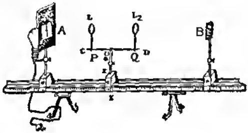


Fig. 1

Description:—Nodal slide bench:—It is an optical bench carrying four stands. An electric bulb closed in a box (not shown in the fig.) is mounted in one stand. There is an opening on one side of the box. A white metal screen with a cross slit is mounted on another stand just before the opening of the box. On one of the stands X, the lens system can be mounted in two lens holders P and Q fixed on a transverse rod CD. (In case of lenses separated by a distance) or the lenses can be mounted in one holder at O (in case of a single lens or in case of lenses placed in contact). The stand X can move as a whole along the bench and its position can be noted on the bench. A small linear scale is also provided on the bed of X on which OX' can be moved with the help of a rack and pinion arrangement. PQ can also be rotated about an axis OX' and its position can be read on the circular scale marked on X. The distance between the two lenses can be adjusted by moving P and Q along the rod CD. Again by shifting the rod CD through O the position of OX' (i. e. axis of rotation) can be shifted from P to Q. On the fourth stand a plane mirror (B) is mounted facing towards the lenses. Some times the lamp is supported on the same stand as the screen.

Theory :—We know that for any thin lens, the position of the object and image is given by $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$ where u is the distance of the

object, v is the distance of the image from the lens and f is the focal length of the lens. We can also locate the image of any object graphically by drawing a few set of rays.

Now consider a co axial system of lenses separated by a certain distance. The image of any object can be located in that system by applying the above relation successively for each lens. The image in one serving as an object for the other and so on. But this method is tedious and cumbersome. Gauss defined a set of points for an optical system such that if they are known in case of any system the position of the image of any object can be located with out knowing the actual nature or details of the system. These points are known as cardinal points or Gauss points. There are 3 such pairs of points (in all six points). This treatment applies to a co-axial system.

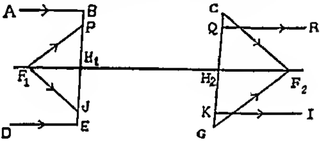


Fig. 2

Focal points :—The point F_1 lying on the axis of the system such that the rays starting from F_1 (or proceeding towards F_1 in case of a divergent system) like F_1P and F_1J after passing through the system go parallel to the axis, is known as First principle focus or focus of the object space. A plane passing through F_1 and perpendicular to the axis is known as first focal plane. Rays diverging from any point on this plane (not on the axis), will go as a parallel beam in the image space. In this case they will not be parallel to the axis. This plane is given by the relation $v=\infty$. Again if rays

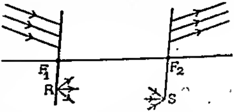


Fig. 3

arallel to the axis are incident on the system, after passing through the ystem they will converge at a particular point (or will appear to diverge from a particular point in case of a divergent system). This point known as second principal focus or focal point of the image space. A lane passing through this point and perpendicular to the axis is known s second focal plane. All parallel rays (which are not parallel to the xis) will converge (appear to diverge from) at any point on this plane.

Principal points and principal planes or planes of unit magnification.—These are two conjugate planes (BE and CG) such that if ny object lies in one of them (BE), its image will lie in the other (CG) This image will be of same size and will lie on the same side of the xis. Therefore these planes are also known as planes of unit magnification. If a ray say F_1P meets the plane BE at a height H_1P, its onjugate ray QR will meet the second plane CG at the same height H_2Q. (i. e. $H_1P=H_2Q$). The points of intersection H_1 and H_2 of hese planes with the axis are known as principal points of the object pace and image space respectively.

Again the distances of the object and image are respectively measured from these planes. The distance of F_1 from H_1 is known as focal length of the object space (F). The distance of F_2 from H_2 is known as focal length of image space (F'). We know that when the medium on both the sides is the same, F=F'.

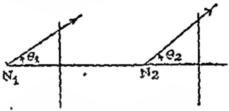


Fig. 4

Nodal points:—These are two conjugate points N_1 and N_2 such that if a ray passes through one of them, its conjugate ray will pass through another and will go parallel to the incident ray. That means their angular magnification is unity $\left(\frac{\tan\theta_2}{\tan\theta_1}=1\right)$. Again the distance between them (N_1N_2) is equal to the distance between two principal points (H_1H_2). (i. e. $N_1N_2=H_1H_2$). We also know that when the

medium is same on both the sides, the two nodal points respectively coincide with the two principal points.

Principle of auto-collimation :—Consider a lens system placed as shown in the figure. M is a plane mirror and P is an illuminated source. If the position of P is so adjusted that the image of P is formed

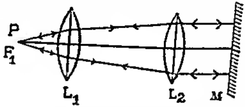


Fig. 5

at the same place i. e. at F, then the rays are falling normally on the mirror and therefore retrace back their path. Since the mirror is normal to the axis therefore the rays falling on the mirror are parallel to the axis. Hence according to the definition P lies at F_1 the focal point of the lens system. The rays after passing through the lens system fall normally on the plane mirror as a parallel beam and retrace back as a parallel beam and are converged by the system back again at P. Thus here plane mirror acts as a collimator as well as reflector. This is known as auto collimation.

Principle of Nodal slide—Consider three parallel rays AB, CN_1 and DL incident on the lens system. They lie in a plane perpendicular to the plane of paper i. e. perpendicular to the vertical plane. Again this plane also makes a certain angle with the horizontal plane passing through the axis. One of these rays CN_1 passes through the nodal point N_1, therefore its conjugate ray N_2P will go parallel to

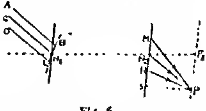


Fig. 6

CN_1 and meets the focal plane at P. Since the rays are parallel to each other they will converge at a point in the focal plane, therefore all the other rays will also come to focus at P. Hence P is the image of the object. Now suppose rotate the system in a horizontal plane about an axis passing through N_2. Suppose we rotate the system in clock wise direction such that N_1 takes the position of B. Now AB will be

passing through N_1 and therefore N_2P will be its conjugate ray because it passes through N_2 and is parallel to AB or CN_1 or DL. Again all the rays will come to focus at P. and it will be the image of the object. Therefore the image will not shift. Similarly on rotating the system in anticlock-wise direction N_1 takes the position of L and now ray DL passes through the nodal point N_1 and again N_2P will be the conjugate ray of DL and the image of the object will be formed at P. Thus on rotating the optical system about the second nodal point N_2 the position of image (P) will remain the same and it will not shift. Conversely if we can find a point N_2 such that on rotating the system about that point the image remains stationary, then the axis of rotation is passing through the second nodal point.

If the medium is same on both the sides the principal points will coincide with nodal points and the distance N_2P_2 will give the focal length of the system.

If f_1 and f_2 are the focal lengths of the two lenses and d is the distance between them then the focal length F of the combination is given by the formula.

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{d}{f_1 f_2}$$

Here F, f_1, and f_2 refer to the focal lengths of the image spaces and are taken as negative for a convex lens and positive for a concave lens.

To adjust the bench —1. Adjust the lamp, slit, lenses and mirror in such a way that their axes lie along the same horizontal line. Put the lenses at some suitable distance (10 or 15 cm). Adjust the slit on some whole number reading. Put the stand O X at 0 of the small scale on X.

To find the focus :—

2. Adjust the position of CD such that OX' is very near to P.

3. Move the lens system as a whole that is move the stand X towards or away from the slit till a clear and well defined image of the cross is formed on the same screen. (i. e. on the cross at slit.) In this position the screen lies at the focal plane of the lens system. Some times the image of the cross may be formed due to reflection from lens surfaces. To distinguish this false image from the required image slightly rotate the plane mirror. If the image is not disturbed then it is the false image while if it is disturbed it is the real image.

4. Now rotate the system slightly about OX' and note the shift of the image. Suppose the shift is towards left.

5. Move the rod CD such that the distance OP increases slightly.

6. Again focus the cross by moving the lens system as a whole i. e. by moving X.

7. Again rotate the system about OX' note the shift of the image.

8. In this way every time shift the axis of rotation towards O and after focussing it again note the shift. Go on doing this till the image shows no shift on rotating the system. In this position the axis OX' is passing through the second nodal point N_2. If the axis is further shifted the direction of the shift of the image will change. Now it will shift towards right.

9. Note the position of X and that of the slit. (screen). The distance between X and the screen (AX) gives the focal length. Provided OX' lies at the 0 of the small scale on the bed of X. If it is not on zero then add or subtract its reading from the above distance to get the focal length.

10. Now rotate the system by 180° and again find out the focal length as shown above and find the mean. Change the position of the slit (A) and again repeat the above procedure. This gives second set Take 4 or 5 sets.

11. Find the mean focal length.

Observations :—

The distance between two lenses =......cm.

Observation table for F.

Set No.	when light is incident on L_1			when the light is incident on L_2			Mean F
	Position of slit (A)	Position of axis OX'	$F=AX'$	Position of slit	Position of axis	F	
1							
2							
3							
4							
5							

Result :—F = ... cm.

Precautions and sources of error:—1 The slit should be properly illuminated.

2. See that false image due to reflection from lens surface is not mistaken for the real image.

3. The rotation should not be more than 4 or 5°.

4. If on moving the axis towards nodal point the image shifts on one side, then on crossing the nodal point it will shift on opposi e side.

Modification :—Verify the formula,

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{d}{f_1 f_2}$$

In this case first find out the value of f_1 and f_2 separately. For this remove the rod CD and mount the lens (L_1) on the holder at O. Now move the lens away from or towards the screen A, till a well defined image of the cross slit is formed on the cross again. Confirm this by slightly rotating the lens about the axis OX'. The image will not shift. Measure the distance of the lens from the cross slits. This givs f_1. Rotate the lens by 180° and again repeat the above. Find out the mean focal length.

Now remove L_1 and mount L_2 in its place and find out its focal length f_2 as shown above.

Now fix up the lens in the slide assembly at a certain distance d apart and find out the focal length F of the combination as shown in the above experiment. Measure the distance d also. Calculate the value of F using the above formula. Campare this value with the experimental value. If the two agree the formula is verified.

Repeat the same experiment for different values of d and verify the above relation in each case.

Observations :—

1. Focal length of lens (L_1), f_1 = ...cm.
2. Focal length of lens (L_2) f_2 = ...cm.

Set. No.	Distance between lenses	Light incident oo	Position of cross slits	Position of axis	Focal length F	Mean F from each set	calculated F
1		one lens					
		other lens					
2		one lens					
		other lens					
3		one lens					
		other lens					

Since the calculated and exeperimental values agree, hence the formula is verified.

Oral questions :—1. Define cardinal points. Focal points, Principal points and Nodal points of an optical system. 2. Why do you call principal planes as unit planes ? 3. What do you mean by the focal length of object space, focal length of image space and focal length of combination ? 4. What is an equivalent lens ? 5. In what respects it is equivalent to the optical system. ? 6. What is the principle of your experiment ? 7. Is this method suitable for a thick lens ? 8. Where do we use combination of two lenses.

OPTICAL LEVER

Use of optical lever. *To measure the depression in case of bending of beam experiment.*

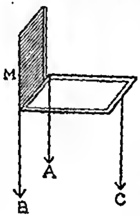


Fig. 2

Description :— It consists of a metallic plate supported on three legs A, B and C. A plane mirror M is fixed perpendicular to the plate and along the line A B. When the instrument is placed on a plane

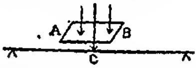


Fig. 1

glass plate A B C, lie in a horizontal plane and M remains vertical. Another part of this lever is a vertical scale and telescope fixed on a stand.

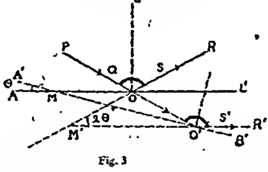


Fig. 3

Theory:—(i) when a mirror rotates by an angle θ, the reflected ray remaining constant the incident ray rotates through an angle 2θ.

(ii) When angles are small $\tan \theta = \theta$.

PART II

(For III year Degree Course)

EXPERIMENT No. 26

Experiment:—To determine the moment of inertia of heel about its own axis.

Apparatus:—Fly wheel, weight box, vernier callipers, atch, thread, meter scale etc.

Description of apparatus:—It consists of a heavy wheel

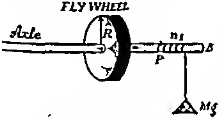


Fig. 1

with a horizontal axis AB mounted on two ball bearings fixed in sockets on a table. The wheel is placed at some convenient height from the ground. The axle carries a hole at P there is a peg into which a loop of a string can be slipped. heel is capable of rotation about a horizontal axis.

Theory:—When a string carrying a mass m. gm is wrapped the axle, and allowed to fall freely under gravity, the is set in rotation. The falling mass loses potential energy ing (i) Kinetic energy of translation to itself, (ii) K. E. of n to the fly wheel, and (iii) doing work against friction by the relation,

$$mgh = \tfrac{1}{2} mv^2 + \tfrac{1}{2} I\omega^2 + Fn_1 \quad \text{..........(i)}$$

h is the height through which the mass descends which is equal to the length of the string.

v is the velocity of the mass when it is detached from the axle.

ω is the angular velocity of the fly wheel when the mass is detached from it.

I is the moment of inertia of the fly wheel

F is the work done against the force of friction for one rotation of the wheel.

n_1 is the number of rotations the wheel makes till the mass is detached from it, which is equal to the

number of turns of the string wrapped round the axle before the mass is made to fall

g is acceleration due to gravity.

If the wheel makes n_2 rotations and takes t secs. before it comes to rest, after the mass has been detached, (it is due to friction), we have,

$$n_2 F = \tfrac{1}{2} I\omega^2 \ldots \quad \ldots \quad \ldots \quad \ldots \quad \text{(ii)}$$

$$\omega = 4\pi n_2 \ldots \quad \ldots \quad \ldots \quad \ldots \quad \text{(iii)}$$

and $v = r\omega t$ ... (iv) where r is the radius of the axle of the fly wheel.

From eqns. (i), (ii), (iii) and (iv) we get

$$I = \frac{m}{n_1+n_2}\left[\frac{ght^2}{8\pi^2 n_2} - n_1 r^2\right] \quad \ldots \quad (v)$$

Method:—1. First of all see that the wheel can rotate freely; if not, oil the bearings so that the friction is reduced.

2. Take a thread whose length is less than the height of the axle of the wheel from the ground. Tie a suitable mass (say ½ k.gm.) to one end of the thread. Form another end into the form of a loop. Slip the loop loosely on the peg P. If there is no peg and only a hole, fit a brass pin in the hole and then put the loop.

3. Wrap the thread around the axle till the mass hanges just near it. The thread should be evenly wound. No two turns should overlap each other. Count the number of turns of the thread (n_1).

4. Now release the mass and allow it to fall freely. Count the number of rotations the wheel describes before the mass falls off and the thread is detached from the axle. It can be done by making a reference mark by a chalk on the fly wheel, and puting a pin by a separate stand in front of the mark. Let it be n_1. Naturally the number of rotations made by the wheel is equal to the number of turns of the thread wound on the axle.

5. When the mass falls off and the thread is just detatched from the axle, start a stop-watch. Count the number of rotations made by the wheel before it comes to rest on account of friction. Let them be n_2. Stop the stop-watch when the wheel stops moving, and determine the time t for which the fly wheel moves after the detachment of the mass. It gives t.

6. Measure the length of the thread. It gives the height (h) through which the mass falls.

7. Find the V. C. of the callipers and determine the diameter of the axle with its help. It should be determined at three to four different places and then mean diameter should be found out.

8. For the same length of the thread and the mass, repeat the procedure to get n_1, n_2 and t.

9. Change the length of the thread, and mass suspended atleast for three times, and for each set take atleast two different observations for n_1, n_2 and t.

10. Calculate the moment of inertia of the fly wheel by each set, and then determine the mean moment of inertia.

Observations:—

1. For the radius of the axle:

(A) L. C. of the vernier callipers. = ... cm

(B) Diameter of the axle

(1) = ... cm. (2) = ... cm. (3) = ... cm. (4) = ... cm.

Mean diameter = ... cm.

Mean radius (r) = ... cm.

2. Acceleration due to gravity = cm./sec^2

3. Length of the thread = cm.

4. For the number of rotations and time t:—

S. No.	Height (h)	Mass suspended in gm.	No. of rotations made by the wheel when the mass is detached (n_1)			No. of rotations made by the wheel after the mass has fallen off (n_2)			Time taken by the wheel to come to rest (t) in sec		
			1	2	Mean	1	2	Mean	1	2	Mean
1.		½ K.gm.									
2.		1 K.gm.									
3.		1½ K.gm.									

Calculations:—

Applying formula (v) calculate I.

For the 1st Set I = gm × cm^2

2nd Set I = "

3rd Set I = "

Mean I = "

Result:—The moment of inertia of the fly wheel= gm × cm²

Precautions and sources of error—1. The friction at the bearings should not be too large. If it is so when the mass is released it will fail to set the wheel in motion. It can be reduced by oiling.

2. *The mass selected should not be so large that when it is detached, the wheel begins to rotate so quickly that it may become difficult to count the number of rotations made by it.*

3. The length of the string should be less than the height of the axle from the ground.

4. The loop placed on the peg should be quite loose. If it is not so when the thread unwounds completely, it will not leave the axle. Rather, it will begin to wound in the opposite direction.

5. The radius of the theread should be very very small in comparison to the radius of the axle. *If it is not so the radius of the thread should be added to the radius of the axle to get r* (beceuse $v = r\omega$)

6. The stop-watch should be started *exactly at the time* when the thread is detached from the wheel.

Criticism:—In this experiment it is pretty difficult to start the stop-watch just at the moment when the mass is detached. It causes error in the determination of n_2 and t. Furthermore, sometimes the wheel does not complete full rotations and hence n_2 cannot be determined very accurately.

The angular velocity of the wheel (ω) has been determined ($\omega = 4\pi n_2/t$) on the assumption that the friction remains constant while ω is reduced from the value ω to o. But it is not true because actually the force of friction is more at small velocities, and hence F does not remain constant. Therefore, if more accuracy is the aim ω should be determined with the help of a tunning fork, where no such assumption is made.

Oral Questions—(1) What do you understand by the term moment of inertia of a fly wheel? What is a fly wheel? (2) Why it has got a particular shape and where is its mass concentrated (3) What is its necessity in a steam engine and automobiles? (4) Why the length of the string taken should be less than the height of the axle from the ground? (5) Can you take a string of quite a large radius, if not, why? (6) Why there should not be much friction at the bearings? If it is so, how can you reduce it? (7) Why the angular velocity (ω) determined by this experiment is not so accurate? Can you suggest some batter method of determining ω? Can the different turns of the thread overlap each other, if not, why?

EXPERIMENT No. 27

Experiment :—To determine the electro-chemical equivalent of copper with the help of a copper voltameter, using a tangent galvanometer.

Apparatus :—A copper voltameter, one similar extra plate of copper, a rheostat, an accumulator, a tangent galvanometer, a stop-watch, sand paper wt. box etc.

Description of the apparatus :— Copper Voltameter: It consists of a glass vessel nearly filled up with 15 to 20% acidulated solution of copper sulphate. Three plates of copper are dipped in the solution as shown in Fig. 1. The two outer plates A A are joined together and are having a common binding screw. They form the anode of the voltameter. The current enters through the anode The middle plate, also carrying a binding screw forms the cathode. The cathode is well insulated from the anode plates, and is movable. It can be taken out, dried and cleaned.

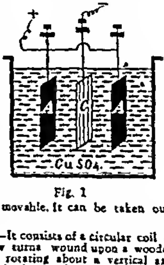


Fig. 1

Tangent galvanometer :—It consists of a circular coil of insulated copper wire of a few turns wound upon a wooden frame. The frame is capable of rotating about a vertical axis fixed at the centre of a circular horizontal disc fixed at the base. The base rests upon three levelling screws. At the centre of the coil, there is placed a cylindrical box covered with glass. The box carries a horizontal circular scale fixed at its base. The scale is divided into four quadrants reading O° to 90.° A small magnetic needle is freely pivoted at the centre of the circular scale. A long and and light alluminium pointer is attached to the needle at right angles to its length. The pointer moves over the circular scale. The base of the box also carries a mirror in which the image of the pointer can be seen. The box is also capable of rotation along a vertical axis.

The two ends of the coil are connected to two binding screws fixed on the base of the instrument. The number of turns are usually written between the two binding screws. Generally the instrument carries three or four coils of different turns each connected to a different binding screw on the base of the instrument. The coils are so arranged that any one or all of them can be put in circuit in series.

Theory:—*The connections are self explanatory. A copper voltameter and a tangent galvanometer are connected in series through a commutator key K, Let i be the current flowing*

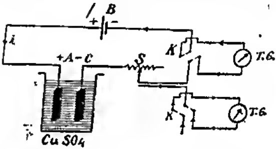


Fig. 2

through the galvanometer, *when its coil is placed in the magnetic meridian* and θ be the angle of deflection of its needle from the magnetic meridian, then, we have,

$$i = K \tan\theta \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (i)$$

where K is the reduction factor of the tangent galvanometer given by the relation,

$$K = \frac{10rH}{2\pi n} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (ii)$$

where r is the radius of the coil, H the horizontal component of the earth's field, and n the number of turns in the coil.

The same current i is flowing through the copper voltameter. Let m be the mass of copper desposited due to this flow of current for an interval of time t. Then, according to Faraday's Law of electrolysis we get,

$$m \propto i\,t$$

$$\text{or} \quad m = e\,i\,t \quad \ldots \quad \ldots \quad \ldots \quad (iii)$$

where e is the electro-chemical equivalent of copper. From equations (i), (ii) and (iii) we get,

$$e = \frac{m}{t} \times \frac{2\pi n}{10\,r\,H \tan\theta} \quad \ldots \quad \ldots \; (iv)$$

Knowing m, t, n, H, r and θ, e can be calculated.

Method:—Remove the cathode plate C from the voltamater. Clean its both the surfaces with sand paper and wash with water. Dry it completely, and weigh it in a sensitive balance. Let its mass be W_1 gm.

2. Fill two thirds of the voltameter with the given copper sulphate solution. In place of the removed copper plate, put the extra plate of copper which is exactly similar to the former. To start with, the latter froms the cathode.

3. Now make the connections as shown in Fig. 2. connect the *anode plate A of the voltameter to the +ve terminal of the accumulator.* (If there are two anode plates instead of one as shown in Fig. I, they are internally connected to the same terminal). Connect the cathode C to the -ve terminal of the accumulator through a rheostat S, tangent galvanometer T. G. and the commutator K. (In case there are two enode plates, the third plate suspended in the middle forms the cathode.)

To adjust the tangent galvanometer:-

4. With the help of a spirit level, make the compass box horizontal by adjusting the levelling screws. Rotate the coil till it is parallel to the small magnetic needle in the compass box. Rotate the compass box keeping the coil fixed till pointer reads zaro-zero on the circular scale. Now pass some current in the galvanometer and note the deflection of the current in the galvanometar with the help of the commutator K, and note the deflection. If it is the same, the coil is in the magnetic meridien. If not so, slightly rotate the coil till the two deflectione are rendered equal.

To adjust the current in the voltameter.:—

5. Close the circuit and adjust the rheostat S, so that the tangent galvanometer gives *a deflection of nearly* 45°, If it is not possible, *the deflection should be between* 35° *and* 60°. Wait for some time and see that the current remeins constant. Now switch off the current.

6. Remove the extra plate from the voltameter. In its place put the weighed plate (see step 1) on which the copper is to be deposited. Now this plate forms the cathode.

To determine the mass (m) of copper deposited:

7. Switch on the current and immediately start the stop-watch. Care should be taken to see that the current should remain constant in the circuit. This can be done by adjusting the rheostat. Read both the ends of the pointer in the tangent galvanometer.

8. After an interval of fifteen minutes, reverse the current in the tangent galvanometer. Again read the two ends of the pointer. Pass the current for the neat fifteen minutes

and then switch off the current, and stop the stop-watch (Current has been passed for nearly 30 minutes).

9. The mean of the four readings taken of the pointer will give the mean deflection θ.

10. Find the time t for which the current has been passed by the stop-watch. It gives t.

11. Remove the cathode plate C, and dip it in a jar filled with water to remove the traces of copper sulphate solution. Now dry the plate by softly pressing its sides by either a filter paper or a blotting paper. When it has completely dried, put it in a balance and weigh it. Let its new mass be W_2 gm.

12. Subtract the former mass W_1 from this new mass W_2 and determine the mass (m) of the copper deposited.

13. Note down the number of turns (n) of the coil used.

14. Determine the radius r of the coil, by measuring the circumference of the coil with the help of a thread. If l is the length, $r = \frac{l}{2\pi}$

15. Find out the value of H at the particular place from standard tables.

16. Knowing all these things, calculate the value of e from formula (iv).

Observations :—

(1) *For determining the mass of copper deposited:—*

(i) Mass of the cathode plate before the deposition of copper (W_1) = ... gm.

(ii) Mass of the cathode plate after the deposition of copper (W_2) = ... gm.

(2) Time (t) for which the current has been passed ..... =...sec.

(3) (i) Number of turns connected (n) =...

(ii) Circumference of the coil (l) =... cm.

(iii) Radius of the coil $r = \frac{l}{2\pi}$ =... cm.

(iv) H =...gauss.

(4) *Table for determining θ :—*

S.N.	Time in sec. (t)	Deflection of tangent galvanometer: Direct: One end	Direct: another end	Reverse: One end	Reverse: another end	Mean θ	tan θ

Calculations :—

1. Mass of the copper deposited $(m)=(W_1-W_2)=...$gm.
2. Knowing m, t, H n, r and $\tan\theta$, calculate the value of e. c. e.

Result :—e. c. e. of copper = ... gm. per coulomb.

Precautions and sources of error :—

1. The tangent galvanometer should be properly levelled, and its plane should *always remain in the magnetic meridian.*

2. All the magnetic materials or the current carrying wires should be kept as far from the galvanometer as possible otherwise the deflection will change.

3. The copper sulphate solution in the voltameter should be made slightly more acidic by adding 0.1% by volume of con. sulphuric acid. It increases the conductivity of the solution. *The area of the cathode plate dipped in the solution, should be nearly 50 sq cm. per ampere, otherwise the deposit will not be smooth, and it may peel off.*

4. The cathode plate should be *thoroughly cleaned and dried before the deposition of copper on it.* If it is not perfectly clean, the deposit will not be smooth.

5. The masses of the plate, before and after deposition of copper should be determined by a sensitive balance preferably weighing up to 1/10th of a milligram.

6. During the performance of the experiment the current in the circuit *should remain constant.* The current strength should be nearly between 1.5 to 2 amp. Very strong currents should not be passed, otherwise the deposit will be brittle.

7. As far as possible, the deflection in the galvanometer should be near *about* 45°. If it is not possible θ in no case be less than 30° and more than 60°.

8. Both the ends of the pointer should be read to avoid the error due to the eccentricity of the pivot with respect to the circular scale.

9. Reading for deflection should be taken first with current passing in one direction, and then after reversing the current. It removes the error if there is any, due to any want of setting of the coil in the magnetic meridian.

Criticism :—

The method is not very accurate, due to the following reasons :

(i) It is very difficult to set the coil of the galvanometer exactly in the magnetic meridian.

(ii) The magnetic needle though very small does not move in a uniform magnetic field.

(iii) There is always some friction present at the pivot of the instrument.

Oral questions :—(1) Why the galvanometer is called a tangent galvanometer ? (2) What is tangent law ? (3) Why the coil of the galvanometer is placed in the magnetic meridian ? (4) Why is it levelled ? (5) Why the current is reversed in the galvanometer? (6) Why magnetic materials should not be placed in its vicinity? (7) What is electrolysis ? (8) What is a voltameter, and what is the electrolyte employed in a copper voltameter ? (9) What do you understand by e. c. e. of a substance ? (10) On which plate the copper is deposited ? (11) Why should this plate be throughly cleaned before depositing copper on it. (12) Why should the current remain constant through out the expt. ? (13) Can you employ large currents, if not, why ? (14) Why do you take two anodes and one cathode ? (15) Can you use a copper voltameter for measuring current ? (16) Why the cathode plate should be weighed by a highly sensitive balance ?

EXPERIMENT No. 28

Experiment.—To determine the internal resistance of a primary cell i.e. a Leclanche cell with the help of a potentiometer.

Apparatus:—A potentiomter, an accumulator, a shunt wire, Leclanche cell, resistance box, two plug keys, connecting wires etc.

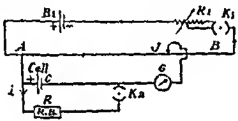


Fig. 1

Description of the apparatus—See experiment No. 17. AB is the potentiometer wire. B_1, R_1, C, R. B. and G are respectively, the accumulator rheostat, Leclanche cell, resistance box and galvanometer. K_2 is a plug key.

Theory:—The connections are self explanatory. Let E and r be respectively the e.m.f. and internal resistance of the Leclanche cell C. If a resistance, R is connected in series with it through a plug key K_2, current flows in it. Consequently, the potential difference across its terminals is lowered. Let the current flowing in the circuit be i, then applying ohm's law, we get,

$$i = \frac{E}{R+r} \quad \ldots \quad \ldots \quad \ldots (i)$$

Let the potential difference across the two terminals of the resistance R be V. V is also the lowered potential difference across the two terminals of the cell in closed circuit (i.e. when current is passing through it). Then again applying ohm's law we get,

$$i = \frac{V}{R} \quad \ldots \quad \ldots \quad \ldots (ii)$$

From equations (i) and (ii) we get,

$$r = \frac{E-V}{V} R \quad \ldots \quad \ldots \quad (iii)$$

Now let l_1, be the balancing length of the potentiometer wire when the e.m.f. E of the Leclanche cell is balanced on it (i.e. when the cell is in the open circuit and K_2 is open). Then we have,

$$E = l_1 x \quad \ldots \quad (iv)$$

where x is the potential gradient along the potentiometer wire.

Let l_2 be the balancing length of the wire when the potentiel difference V across the pletes of the cell is balanced on it (i.e. when K_2 is pressed and the the cell ie short circuited). Then we have,

$$V = l_2 x \quad \ldots \quad (v)$$

Substituting the values of E and V from eqns. (iv) and (v) in eqn. (iii) we get,

$$r = (\frac{l_1}{l_2} - 1) R$$

knowing l_1, l_2 and R, r can be calculated.

Method:—1. Make neat and tight connections as shown in Fig 1. Connect the *end A of the pontentiometer wire to the +ve terminal of the accumulator B_1*, and the end B to the -ve terminal of the accumulator through the rheostat R_1 and key K_1. Evidently *the potential of A is higher than that of B.* It constitutes the primary circuit.

2. Connect the *+ve pole of the Leclenche cell* C to the end A, and its *—ve pole to the jockey j* through a galvanometer G. Put a shunt across the galvnometer.

3. Connect a resistance box R. B. across the two polee of the cell C through a plug key K_2.

4. Keeping K_2 open, close the key K_1, and test for the correctness of the connections. Move the jockey J to one end of the potentiometer wire and press Note. the direction of deflection in the galvanometer. Now move J to the other extreme end of the wire and press. Again note the direction of deflection in the galvanometer. If this deflection is opposite to the previous one, the connections are correct. If not eo, either the connections are wrong, or the potential differene across the ends A and B ie less than the e. m. f. of the cell. To increase p. d. across AB reduce the resistence io the rheostat R_1, so that the deflection becomes two sided.

To determine l_1:—

5. After testing for the correctness of the connectione determine the balancing length of the potentiometer wire

corresponding to the e. m. f. E of the Leclanche cell (i. e. when it is in open circuit). It can be done by adjusting jockey J for no deflection in the galvanometer. The resistance R_1 in the rheostat should be so adjusted that this balance point is obtained nearly on the last wire. The final adjustment must be done by removing the shunt wire. It gives l_1.

To determine l_2 :

6. Keeping the resistance in the rheostat R_1 constant, close the key K_2, and introduce some resistance, say, 5 ohms in the resistance box. Now the cell is in the closed circuit. In this position, again determine the balancing length of potentiometer wire corresponding to the lowered p. d. (V) across the two plates of the cell C. Shunt should be removed while making final adjustment. It gives l_2.

7. Repeat the above procedure, and determine l_1 and l_2 by increasing the resistance R in R. B. in steps of 1 to 2 Ω. In this way take four to five observations. See that for one set of l_1 and l_2, R_1 remains same.

8. Now change the resistance in R_1 and repeat the above procedure to get a new set of readings for l_1 and l_2.

9. Knowing l_1, l_2 and R calculate r by each set.

Observations:—

S. N.	Balancing length of the wire: When the cell is in open circuit (l_1) (in cm.)	Balancing length of the wire: When the cell is in closed circuit (l_2) (in cm.)	Resistance R in R. B. (in ohm)	Internal resistance $r=\left[\frac{l_1}{l_2}-1\right]R$ (in ohm.)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Calculations :—Calculate the value of r by each set, by the formula,

$$r=\left[\frac{l_1}{l_2}-1\right]R$$

[illegible]

Result:—The internal resistance of the the cell varies between [illegible]

Precautions and sources of error:—1. See expt. nos. 17, 18 and 19.

2. The accumulator should be fully charged, and must be of fairly large capacity, so that, the current in the primary circuit may remain constant. If not so, the potential gradient will not remain constant.

3. The rheostat R_1 should be so adjusted that the balance point in the open circuit is obtained on the last wires of the potentiometer. It increases l_1 and hence the sensitivity of the instrument.

4. The +ve terminal of the *Leclanche* cell should be connected to the +ve end of the potentiometer wire.

5. The resistance in R_2 should never be changed in the same set while taking observations for l_1 and l_2.

6. While obtaining approximate balance point the galvanometer should always be shunted.

Criticism:—The internal resistance of the cell changes according to the current drawn from it. More is the current drawn greater will be the value of the internal resistance. It is due to the increasing polarisation of the primary cell. However, the e.m.f. of the cell is determined when it is in open circuit. *Therefore, this method is far more superior to that of voltmeter* ammeter method of determining internal resistance. The method is not suitable for measuring the internal resistance of an accumulator, because to obtain appreciable fall in p.d., very large currents should have to be drawn, which may spoil the plates of the same.

Oral questions :—

1. *See expt. Nos. 17, 18, 19.* 2. What *do you understand* by the internal resistance of a cell? 3. Does it remain constant if not, why? 4. How can you measure it with the help of a potentiometer? 5. Is this method superior to that of voltmeter, ammeter method *of measuring internal resistance?* 6. *Can you measure the internal resistance* of an accumulator by this method? 7. Why should the accumulator used be of fairly large capacity and constant e.m.f? 8. What order of resistances be introduced in the cell circuit while short circuiting it? 9. Why the readings for l_1 should be checked occassionally? 10. Why the current should be kept constant while taking one *set of readings for l_1 and l_2?*

———

EXPERIMENT No. 29

Experiment :—To determine the internal resistance of an accumulator with the help of an ammeter and a milli-voltmeter.

Apparatus:—Two similar accumulators of exactly or nearly the same e.m.f., an ammeter (nearly of 1 amp. range), a milli-voltemeter (100 milli-volt range), a rheostat, plug key, tapping key, connecting wires etc

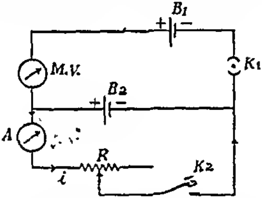


Fig. 1

Theory:—The connections are self explanatory. If B_1 and B_2 are of exactly the same e.m.f., the reading in the milli-voltmeter will be zero. However, even if there is a slight difference in the e.m.fs of the two cells, the milli-voltmeter will give some reading. Now if k_2 is pressed, current will flow through the cell B_2 and the resistance R. Consequently, the potential difference across the two plates of the cell B_2 will fall. (No current will flow through the cell B_1, because milli-voltmeter possesses high resistance). Let this drop in potential difference be V, which will be registered by the milli-voltmeter. Let the internal resistance of the cell B_2 be r and the current flowing through it be i. Then applying ohm's law to the lower circuit, we get,

$$r = \frac{V}{i}$$

Knowing V and i, r can be calculated.

Method - I. [illegible]

2. [illegible] (The e.m.f. [illegible] of the same e.m.f.)

3. With the tapping key K [illegible] open close the plug key K [illegible] and note down the reading of the milli-voltmeter. If the two cells are exactly of the same e.m.f. this reading will be zero, otherwise milli voltmeter will give some deflection. Note down this reading. Let it be X.

4. Close K_2 so that current flows through the cells B_1 and [illegible] Consequently, the deflection in milli voltmeter changes. By changing the value of the resistance in the rheostat adjust the current in the ammeter to nearly 0.1 amp. Now find out the reading in the milli voltmeter. Let it be Y. Determine the current i flowing through B_1 by the ammeter A. It completes one set.

5. Determine the difference between the two readings of the milli voltmeter, which will give the drop in potential difference V i.e. $Y-X=V$.

6. Knowing V and i, calculate r.

7. Change the value of the resistance R, and take at least 5 to 7 different sets of reading by altering current in steps of 0.1 amp. (e.g. 0.1, 0.2, 0.3 ...and so on). Calculate the drop in potential V for each set and find r.

8. Determine the mean value of the internal resistance r.

Observations:—

1. Least count of milli voltmeter = ...milli-volts

= ....volts

2. Least count of ammeter = ...amp.

S. No.	Reading in the milli-voltmeter in milli volts		Drop in potential V	Current i in amp.	Internal resistance $r=\frac{V}{i}$ ohm
	when K_2 is open, K_1 is pressed X	when K_1 & K_2 both are pressed Y	(Y-X) in milli-volts		
1					
2					
...					
...					
...					
6					
7					

Calculations:—Calculate r by each set and then determine the mean value of r.

Result:—The internal resistance of the accumulator $(r)=$ ... . ohm.

Precautions and sources of error :—

1. As far as possible the two accumulators must be of the same e.m.f. If there is a difference between their e.m.f.s, it should in no case exceed a few milli-volts, otherwise it would not be possible to take readings in the milli-voltmeter.

2. As the drop in potential V is very small, only a milli-voltmeter should be employed to measure it.

3. The two cells should be fully charged, otherwise the initial reading of the milli-voltmeter will not remain constant.

4. The +ve terminal of the cell possessing higher e.m.f. should be connected to the +ve terminal of the milli voltmeter.

Criticism of the method :—

It is a fairly good method, because milli-voltmeter is employed.

Oral Questions :—

1. What is an accumulator, and how does it differ from a primary cell ? 2. Describe the two types of accumulators, which is better and in what circumstances ? 3. What is internal resistance of an accumulator, and how is it determined ? 4. Can you find it by ordinary voltmeter, ammeter method or potentiometer method, if not, why ? 5. Why the two accumulators should possess nearly the same e.m.f. if not so, what will be the harm ? 6. Why the comparison cell should possess higher e.m.f., if not equal ? 7. Can you use a ordinary voltmeter ?

EXPERIMENT No. 30

Experiment:— *To study the variation of magnetic field with distance, along the axis of a circular coil carrying current graphically, and hence to determine the radius of the coil with the help of the graph.*

Apparatus:— *Stewart and Gees type of tangent galvanometer, accumulator possessing a fairly large capacity, rheostat, commutator, connecting wires etc.*

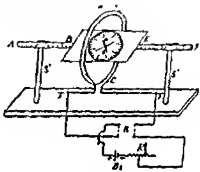
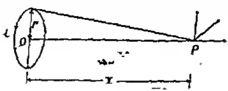


Fig. 1

Description of the apparatus:— This type of tangent galvanometer consists of a circular coil C C having a number of turns of copper wire fixed on a horizontal wooden bench. The coil is fixed in the vertical plane. A magnetic compass box with meter scales AB and EF attached to its either side is mounted at its centre. The scales rest and can slide on the two vertical supports S' S' fixed on the wooden bench. The mangetometer compass box can slide on either side of the coil, such that the centre of the magnetic needle NS always remains on the axis of the coil. The distance between the centre of the needle and the coil can be determined with the help of meter scales AB and EF.

Theory:— The magnetic field F, due to a circular coil carrying current at any point P situated on its axis, at a distance



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:lation,

$$F = \frac{2\pi n r^2 i}{(x^2+r^2)^{3/2}} \quad \dots \quad \dots \quad (i)$$

Where i is the current flowing through the coil, n the number of turns in it, and r its radius.

If the coil is placed in the magnetic meridian, F will act at right angles to the earth's horizontal field H. Consequently, under the influence of these two perpendicular fields, the magneto meter needle will be deflected Let θ be the deflection of the needle from the direction of H. Then, applying tangent law we get,

$$F = H \tan\theta \quad \dots \quad \dots \quad (ii)$$

From (i) and (ii) we get

$$F = \frac{2\pi n i r^2}{(r^2+x^2)^{3/2}} = H\tan\theta \quad \dots \quad \dots \quad (iii)$$

Thus, to study the variation of magnetic field with distance, a graph may be plotted between x and $\tan\theta$ taking distances as *abscissae* and corresponding values of $\tan\theta$ as ordinates.

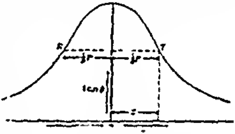


Fig. 3

The curve will be as shown in Fig. 3. At $x = 0$ the curve is concave towards the origin O. The curvature goes on decreasing with x increasing, and for a certain value of x the curve changes sign i. e. it becomes convex towards O (e. g. at R and T in Fig. 3). These points are known as points of inflection. At these points the rate of charge of field is constant.

$$\frac{d^2F}{dx^2} = 0 \quad \dots \quad \dots \quad \dots \quad (iv)$$

Differentiating equation (iii) twice and comparing it with equation (iv), we get,

$$x = \tfrac{1}{2} r \quad \dots \quad \dots \quad (v)$$

Thus, the distance between the two points of inflection R and T situated on either side of the curve will be equal to the radius of the coil.

Method:—1. By sliding the compass box bring the magnetic needle at the centre of the coil C C, and level the compass box with the help of a spirit level.

EXPERIMENT No. 30

Experiment:—To study *the variation of magnetic f* with distance, along the axis of a circular coil carrying cur graphically, and hence to determine the radius of the coil w the help of the graph.

Apparatus:—Stewart and Gees type of tangent galva meter, accumulator possessing a fairly large capacity, rheost commutator, connecting wires etc.

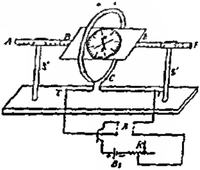


Fig. 1

Description of the apparatus:—*This type of tangent* galvanometer consists of a circular coil C C having a number of turns of copper wire fixed on a horizontal wooden bench. The coil is fixed in the vertical plane. A magnetic compass box with meter scales AB and EF attached to its either side is mounted at its centre. The scales rest and can slide on the two vertical supports S′ S′ fixed on the wooden bench. The *mangeto-*meter compass *box can slide on either side of the coil, such that the centre of the* magnetie needle NS always remains on the axis of the coil. The distance between the centre of the needle and the coil can be determined with the help of meter scales AB and EF.

Theory:—*The magnetic field F, due to a circular coil* carrying *current at any point P situated on its axis, at a distance*

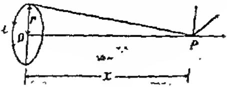


Fig. 2

from its

11. Find out the two points of inflection on the graph and determine the distance between their X-Co-ordinates. It will give the value of the radius of the coil.

Observations :—

S.N.	Distance of the needle from the centre of the coil (x)	Compass box on left hand side						Compass box on the right hand side.					
		Deflection					$\tan\theta$	Deflection					$\tan\theta$
		Direct		Reverse		Mean θ		Direct		Reverse		Mean θ	
		one end	another end	one end	another end			one end	another end	one end	another end		
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													

2. Now to set the coil in the magnetic meridian, rotate the bench in the horizontal plane till the coil, the magnetic needle NS and the scale all lie in the same vertical plane. Now the two ends of the pointer in the box should read 0 0 on the circular scale. If not, rotate the compass box till pointer reads 0-0.

3. Without disturbing the position of the bench, connect the two ends of coil T T to the battery B, through a rheostat R and a commutator.

4. Now allow the current to flow in the coil, and adjust its value with the help of the rheostat R, so as to obtain a deflection of nearly 75° in the compass box at the centre of the coil. (If so much deflection is not produced by one accumulator make use of more number of cells.). Reverse the current in the coil by commutator, and see whether the deflection remains the same. If it varies by more than 2°, slightly rotate the coil so as to obtain almost the same deflection. When the two deflections are equal the coil is set in the magnetic meridian.

5. After setting the coil in the magnetic meridian re both the ends of the pointer. Reverse the current and again re both of its ends. Mean of these four readings will give t deflection θ of the needle at the centre of the coil.

6. Keeping the current in the coil constant, (i. e., on the rheostat is set, it should not be disturbed through out th experiment), move the compass box either towards the right o left of the coil by a distance of, say, 2 cm. The distance fro the centre can be measured with the help of the scales attache to the box. Read both the ends of the pointer, reverse th current and again read both of its ends. Mean of these fou readings will give the deflection of the needle at this point.

7. In this way go on moving the compass box in step 2 cm. till the deflection is reduced to nearly 15°. At each ste take four readings of the pointer and then determine the mea value of the deflection θ.

8. Repeat the same procedure on the other side of the coil, by taking readings of the deflection after every 2 cm. So, in this way the values of θ corresponding to various distances are obtained on both the sides of the coil.

9. *Near about the points of inflection, the deflection of needle should be obtained after every cm. because the curve comes almost vertical.*

10. Knowing deflections at various distances, plot a graph between the distances of the needle from the centre of coil (i. e. x) and the corresponding tangents of deflection (i.e. $\tan\theta$). *If x is taken +ve on the right hand side of the coil, it will be -ve on the left hand side of the coil.* The curve is symmetrical on either side of the centre of the coil.

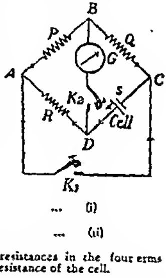
EXPERIMENT No. 31

Experiment:—To determine the internal resistance of a cell by Mance's method either using a meter bridge or a post office box.

Apparatus:—A meter bridge or a post affice box, a sensitive galvanometer, a high resistance like water resistance, resistance box in case of meter bridge, plug keys, given primary cell either a Leclanche cell or a Daniell cell.

Description of the apparatus—You are quite familiar with a meter bridge and a Post Office Box.

Theory:—The theory is the same as that of the Wheat stone net except that *the fourth arm is replaced by the cell and in the cell conjugate arm a key K_1 is introduced.* Even when the cell key K_1 is not pressed, current i_g is flowing through the galvanometer, and it gives deflection when K_1 is pressed. Now this current i_g is independent of the resistance in the arm AC only when the Wheat-stone condition is satisfied. That is, by pressing the key K_1, or keeping it open the value of current i_g flowing through the galvanometer remains unaffected, if



$$P/Q = R/S \quad \ldots \quad \ldots \quad (i)$$

or

$$S = \frac{Q}{P} R \quad \ldots \quad \ldots \quad (ii)$$

Where P, Q, R, S are the resistances in the four arms respectively, S being the internal resistance of the cell.

In case of a meter bridge Q/P is known in terms of the length of the bridge wire L and $L' = 100 - L$; where L and L' are the lengths corresponding to R and S in place of P and Q.

Hence,
$$S = R\,\frac{L'}{L} \quad \ldots \quad \ldots \quad (iii)$$

Calculations:—Find out the radius of the coil by getting the distance between the X-co-ordinates of the two points of inflection.

Result:—The radius of the coil. = ... cm.

Precautions and sources of error:—1. The plane of the coil should lie in the magnetic meridian otherwise the tangent law will not apply.

2. As the current should remain constant through out the experiment an accumulator of large capacity should be employed. Moreover, after taking four or five observations, the compass box should be brought at the centre of the coil, and it should be ensured that the current flowing is the same. If not so, adjust it with the help of the rheostat.

3. To remove the error caused by the eccentricity of the pivot both the ends of the pointer should be read.

4. No magnetic materials or current carrying conductors should be placed in the vicinity of the coil. Even the rheostat R should be kept sufficiently far away from the coil.

5. The deflection of the needle should be taken for both direct and reversed currents, so that even if there is any want of non-coincidence of the coil with the magnetic meridian the error will be eliminated.

6. The pivot of the needle should be as far as possible frictionless.

7. The curve drawn should be smooth and the two points of inflection should be carefully found out.

Criticism:—The results obtained in this method are not very accurate due to the following reasons:—

(i) The coil may not lie exactly in the magnetic meridian.

(ii) It may not be perfectly circular.

(iii) It is not infinitely small, and its centre may not lie exactly on the axis of the circular coil.

(iv) The friction at the pivot is not negligibly small. Further, it is not very easy to accurately locate the position of the points of inflection on the curve.

Oral Questions:—1. See expt. No.16 (Questions on deflection magnetometer). 2. What is the direction of the magnetic field at the centre of the coil ? 3. How does this magnetic field very along the axis of the coil. 4. Where is it maximum ? 5. In which units is the current expressed in this formula ? 6. What is the practical unit of measuring current ? 7. What are points of inflection ? 8. How can you find out the radius of the coil by knowing the points of inflection ? 9. What type of curve between x and $\tan\theta$ you get

this point by moving the jockey slightly to left and right and note change in deflection. (on pressing key K_1)

If the bridge is not very sensitive, you will find that there is a range of wire over which the balaoce point occurs. In such a case note the range and middle point of this range would be the balance point.

Also please note that when the variable contact is made at various points, the galvanometer deflection does not remain constant and as such on pressing the key K_1, the change in direction should be carefully noted.

4. Note the balance point. Measure the length AB i.e. l corresponding to the resistance P and $100-l$ corresponding to Q.

5. To eliminate the end correction.—To do it, the position of the cell and the unknown resistance should be interchanged. Proper precaution must be taken to see that the pressure of tightness of connections, length of connecting wires etc., should as far as possible remain unaffected.

As explained above, again obtain the balance point. Now let the length AB be l' Then this l' corresponds to $100-l$ and $100-l'$ corresponds to l. Take mean of l and $100-l'$ and call it L. Then L and $L'=100-L$ respectively correspond to P and Q.

6 Using the formula given in theory, find out the internal resistance of the cell.

7. Now from the resistance box R, take out the resistance plug corresponding to this resistanca and repeat the above procedure. You will now get balance point approximately in the middle of the wire.

8. Repeat the above procedure by slightly changing the resistance a little more or less than the above value (Every tima do not forget to interchange the cell with resistance R)

9. Calculate r, by each observation, and then determine its mean value.

NOTE—If galvanometer is connected in place of K_1 balance point can be obtained by simply pressing the jockey. Only a wire is connected between BD.

Observations—1. The deflection of the galvanometer is at ......division.

2. When the jockey is pressed at extreme left end the deflection increases/decreases.

3. When it is pressed at extreme right end, the deflection increases/decreases.

Therefore, connections are correct.

In P. O. Box $\frac{Q}{P}$ is known from the ratio arms. R is known resistance which need adjustment for balance point.

Method.—I (1) By meter bridge:—Connections are made as shown in Fig. 2. A high adjustable resistance (preferably water resistance not shown in figure) should be connected in series with galvanometer in between the terminals B and D.

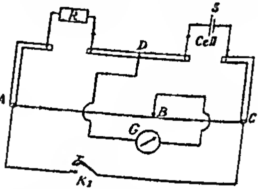


Fig. 2

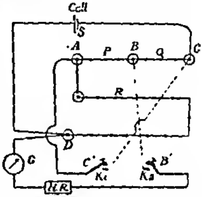
Failure in doing it might lead to the damage of the galvanometer due to excessive flow of current. If you are using a weston type of moving coil galvanometer, adjust the resistance till you get *more than half scale deflection*. From the resistance box R remove the plug corresponding to resistance 1 or 2 ohm. It is better to use key K_1 as contact key and not as plug key.

2. To Test whether the connections are correct:—On making connections there would be deflection in the gavanometer. Adjust the variable resistance so that the deflection is not excessive. Now press the contact key K_1. Keeping the position of the variable key to the extreme left, note the *change in direction of deflection* Now take the jockey to the extreme right and reapeat the above procedure, *if you find that the change in deflection is to the opposite side*, the connections are correct

3. To find the balance point:—In order to find the balance point i.e. the point on the wire AC, where when contact is made with the jockey, *no change in deflection in the galvanometer should occur*, repeat the above procedure at various places. At one particular point, say B you will find that on pressing the jockey, the galvanometer deflection remains unaffected. Confirm

Result:—The internal resistance of the cell = ... ohm.

(ii) By Post Office Box:—1. Make connections as shown in the diagram; usually two tapping keys K_1 and K_2 provide contact between A and C, and B and D. Connect the galvanometer between the terminals B and D through a high variable resistance, and the key K_2. Connect the cell (*which is usually connected between the terminals A and C*), between C and D i.e. in the unknown *resistance arm*. Join the terminals A and C by a thick copper wire through the tapping key K_1. Normally the cell is put between these two terminals. Thus, now P, Q are the ratio arms, R is the known resistance, and S is the unknown cell resistance. Adjust the high variable resistance in series with the galvanometer so that if it is a weston moving coil galvanometer, obtain *more than half the scale deflection*, when the key K_2 is pressed.



2. To test whether connections are correct:—Take out 10 ohm. plug each from P and Q arm. When R=O, press key K_2, and galvanometer will give deflection. Note the direction of this deflection, and press K_1. Now note the change in the direction of deflection in the galvanometer. Make $R=\infty$ or of very lerge value and repeat the above procedure. If you find, that the change in direction of deflection is opposite, connections are correct.

3. Keeping the ratio P : Q as 10 · 10 very the resistance R from zero in steps of 1 ohm till by pressing the key K_1, the constant deflection in the galvanometer changes its direction. Then the resistance of the cell lies between these two resistances (i.e, if for R=1 ohm, deflection in the galvanometer changes its direction towards left, and for R=2 ohm towards right, then the resistance of the cell lies between 1 and 2 ohm).

4. Now make the ratio P : Q as 100 : 10, and determine the same limit of the resistances between which the deflection changes its direction. It gives the resistance of the cell correct upto 1/10th of an ohm.

5. Ultimately make the ratio P : Q as 1000 : 10, and adjust the resistance in R in such a way that the pressing of the key K_1 does not change the deflection of the galvanometer. It

4 Known resistance is in the left gap.

S. N.	Known Resistance R in ohm.	Range of Balance point from......... to......cm.	Balance point	Length corresponding to known resistance i.e. l cm. (P)	Length corresponding to un-known resistance i.e., $100-l$ (cm.) (Q)
1.					
2.					
3.					
4.					

5. Known resistance in right gap.

S. N.	Known Resistance R in ohm.	Range of Balance point from......... to..... cm.	Balance point	Length corresponding to unknown resistance i. e. l' cm. (Q)	Length corresponding to known resistance i. e. $100\text{-}l'$ cm. (P)
1.					
2.					
3.					
4.					

Calculations:—

S. N	Known Resistance R	Mean of l and $100\text{-}l'$ i.e. L cm. (P)	Mean of l' and $100\text{-}l$ i.e. L' cm.	$S = R\frac{L'}{L}$ ohm.
1.				
2.				
3.				
4.				

Internal resistance of the cell $S = R\frac{Q}{P}$

$= R\frac{L'}{L}$

$= \ldots \ldots$ ohm.

Precautions and Sources of error:—1. The resistance of the cell is usually not very high. The connecting leads used for connections must therefore be thick and short.

2. It is always better to use the key K_1 in the galvanometer circuit. Though a separate key in series with the cell is not advised, it is better to use it. Still better would be to remove the zinc rod of the cell and put it inside only when we are in a position to start the work. This however disturbs the cell and changes its internal resistance. Therefore see, that the zinc rod used is well amalgamated and then keep it inside the cell and use a key in series.

3. When there is want of balance, the change in galvanometer deflection will depend on the strength of current which flows between A and C. This again will depend on the resistance in the arm AC—smaller it is better it will be. Therefore, see that the contact key between A and C is connected through thick copper wire.

4. In the case of meter bridge, the balance point should be nearly in the middle. For this the known resistence must be approximately equal to the unknown resistance. This ensures maxium sensitiveness.

5. Interchange of positions of known and unknown resistances is necessary in the case of meter bridge, because that eliminates end corrections.

6. If the deflection (initial) in the galvanometer is very large, small changes in deflection on pressing the key may not be detected, So a large current must flow through the circuit but the current flowing in the galvanometer should not be very large. A convenient deflection would be half the scale deflection.

7. When the ratio arms are changed, the magnitude of galvanometer deflection also changes. This should be carefully noted before pressing the contact key K_1.

8. When the jockey key is moved along the wire see that it is not kept pressed. Also the pressure which we apply to the key should be gentle. This helps in keeping the uniformity of the wire.

9. Remember that the internal resistance of a cell depends on the strength of current drawn. Also it changes due to some changes at the plates.

10. In this experiment it is important to see that the galvanometer key K_1 is pressed first before the cell key K_1 .

Criticism:—This method is not very accurate, because the internal resistance of the cell changes, as the current drawn from it. Furthermore, the polarisation taking place is changing p.d. across the plates of the cell, consequently, the steady deflection

gives the balance point, and the resistance of the cell can be obtained correct to 1/100th of an ohm.

6. Now put the galvanometer in the arm AC, and simply a key in the arm BD i.e. their positions have been interchanged. Again repeat the above procedure. to get the internal resistance. The interchange is necessary to know as to when the bridge is more sensitive.

NOTE—If a moving coil suspended type of galvanometer is used, use lamp and scale arrangement. First level the galvanometer, and put it in series with a variable high resistance so that a very small amount of current flows through it. Now unclamp its coil, and throw light on the mirror to get a bright spot of reflected light on the scale. When the current is passed through the galvanometer, its coil gets deflected. Thus, the spot also gets deflected. Hence in this case the spot of light moves over the scale, and therefore the direction of deflection of the spot should be noted. Rest of the procedure is the same as described above in the method. This type of galvanometer is more sensitive than that of the pivoted type.

Observations:—

N.	Ratio arms Q in ohm.	Ratio arms P in ohm.	Known Resistance R in ohm.	Change in direction of deflection in the galvanometer	Inference	Unknown resistance of the cell $S = R\frac{Q}{P}$ in
	10	10	0 ∞	Left Right	Connections are correct	lies O
	10	10	1 2	Left Right	Less More	lies 1 and
	10	100	16 17	Left Right	Less More	lies 1.6
	10	1000	165	No change	Equal	S=1

Result—The unknown resistance of the cell = ... ohm.

EXPERIMENT No. 32

Experiment:—To determine the internal resistance of galvanometer by Kelvin's method using a P. O. Box.

Apparatus:—A Post Office Box, the given galvanometer whose resistance is to be determined, a variable high resistance (preferably a water resistance), a Leclanche cell , connecting wires etc.

Description of the apparatus:—You are quite familiar with a P. O. Box.

Theory:—The theory of this experiment is also the same as that of the Wheatstone net, except that *in the fourth unknown resistance arm galvanometer is put as shown in fig 1 In the galvanometer conjugate arm, a tapping key K_2 is introduced.* When the cell key K_1 is pressed, current flows in the galvanometer and *it gives deflection.* Now this current is independent of the resistance *in the arm BD* only when the Wheatstone condition is satisfied. That is, by pressing the key K_2 or keeping it open, the value of the current flowing through the galvanometer should remain unaffected, if

$$P/Q = R/S \quad \ldots \quad \ldots \quad \text{(i)}$$

$$\text{or} \quad S = \frac{Q}{P} R \quad \ldots \quad \ldots \quad \text{(ii)}$$

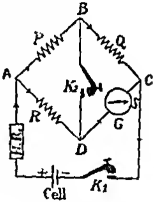


Fig. 1.

where P, Q, R, S, are the resistances in the four arms respectively, S being the resistance of the galvanometer.

In P. O. box P/Q is known from the ratio arms, and R is known resistance in the AD arm, which is adjusted to get the balance point. Knowing P, Q and R, S can be calculated.

of the galvanometer does not remein constant, hence null point cannot be obtained very eccuretely, In this experiment the galvanometer generally becomes insensitive when the ratio $P:Q$ is made 1000 : 10, and therefore internel resistance cannot be determined accurately. Potentiometer method of determining internal resistance is superior to this method.

Oral Questions:—1. What is a Wheatstone net ? 2. Give the construction of e P. O. Box, and show how it supplies the Wheatstone's net ? 3. How are the resistences arranged in e P. O, Box ? 4. Show how these resistance coils are made ? 5. Why the wires are doubled end then wound ? 6. What do you understand by the internal resistance of a cell ? Does it remain constant ? If not why ? 7. How do you determine the internal resistance of a cell by a P. O. Box ? 8. Why the cell arm AC is short circuited by a thick copper wire ? 8. Which key should be pressed first in this experimenc end why ? 10. Is this an accurate method of determining internel resistance ? If not why ? 11. Cen you suggest any better method ? 12 What are the conjugate erms in this method ? 13. Are the points B and D at the same potential when the belance point is obteined ? 14. What are the factors upon which depend the internal resistence of e cell ? 15. Is it necessary to use a key in series with the cell ? 16. Can you determine the internal resistance of en accumulator by this method ?

EXPERIMENT No. 32

Experiment:—To determine the internal resistance of galvanometer by Kelvin's method using a P. O. Box.

Apparatus:—A Post Office Box, the given galvanometer whose resistance is to be determined, a variable high resistance (preferably a water resistance), a Leclanche cell , connecting wires etc.

Description of the apparatus:—You are quite familiar with a P. O. Box.

Theory:—The theory of this experiment is also the same as that of the Wheatstone net, except that *in the fourth unknown resistance arm galvanometer is put as shown in fig 1. In the galvanometer conjugate arm, a tapping key K_2 is introduced.* When the cell key K_1 is pressed, current flows in the galvanometer and it *gives deflection.* Now this current is independent of the resistance *in the arm BD* only when the Wheatstone condition is satisfied. That is, by pressing the key K_2 or keeping it open, the value of the current flowing through the galvanometer should remain unaffected, if

$$P/Q = R/S \quad \ldots \quad \ldots \quad \text{(i)}$$

$$\text{or} \quad S = \frac{Q}{P} R \quad \ldots \quad \ldots \quad \text{(ii)}$$

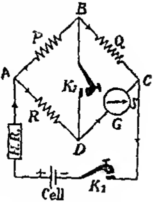


Fig. 1.

where P, Q, R, S, are the resistances in the four arms respectively, S being the resistance of the galvanometer.

In P. O. box P/Q is known from the ratio arms, and R is known resistance in the AD arm, which is adjusted to get the balance point. Knowing P, Q and R, S can be calculated.

of the galvanometer does not remain constant, hence null point cannot be obtained very accurately. In this experiment the galvanometer generally becomes insensitive when the ratio P : Q is made 1000 : 10, and *therefore internal resistance* cannot be determined accurately. Potentiometer method of determining *internal resistance is superior to this method.*

Oral Questions:—1. *What is a Wheatstone net ?* 2. Give the construction of a P. O. Box, and show how it supplies the Wheatstone's net ? 3. *How are the resistances arranged in a* P. O. Box ? 4. Show how these resistance coils are made ? 5. Why the wires are doubled and then wound ? 6. *What do you* understand by the internal resistance of a cell ? Does it remain constant ? If not why ? 7. How do you determine the internal resistance of a cell by a P. O. Box ? 8. *Why the cell* arm AC is short circuited by a thick copper wire ? 8. Which key should be *pressed first in this experiment* and why ? 10. Is this an accurate method of determining internal resistance ? If not why ? 11. Can you suggest any *better method ?* 12 What are the conjugate arms in this method ? 13. Are the points B and D at the same potential when the balance point is obtained ? 14. What are the factors upon which depend the internal resistance of a cell ? 15. Is it necessary to use a key in series with the *cell ?* 16. Can you determine the internal resistance of an accumulator by this method ?

Oral Questions:—1. See Experiment No. 31. 2. What do you understand by the resistance of a galvanometer. How is it determined by this method ? 3. What are the four arms of the Wheatstone's net in this experimental arrangement ? 4. Why the arm BD is short circuited by a thick copper wire ? 5. Why a high variable resistance is connected in series with the cell ? 6. Which key should be pressed first in this experiment and why ? 7. Are the points B and D of the bridge at the same potential when the balance point is obtained ? 8. Do you know any other method of determining resistance of a galvanometer ? 9. Which gives better results, this or the method just mentioned ? 10. What are the conjugate arms in this arrangement ? 11. When is the bridge most sensitive ?

NOTE : Quite a number of *times particularly using the ratio* $Q/P = \frac{1}{100}$, the bridge becomes insensitive, and then for a number of resistances you get balance point. In such cases find *out the range in which the balance point is obtained.* Then the mean reading will give the correct resistance.

Calculations:—$S = Q/P \times R = \ldots$ ohm.

Result:—The resistance of the galvanometer = ... ohm.

Precautions and sources of error:—1. See experimen

2. All the connections should be tight and no plu
P. O. box should be left loose.

3. An accumulator should not be used in this expe
because constant current is not required. Furthermore,
heat the wires altering their resistances.

*4. The battery key K_1 should be pressed firs
there after the galvanometer key K_2 should be pressed.*

5. The terminals B and D should be short circuite
a thick copper wire of only necessary length so that it ma
negligible resistance. Because when there is lack of balan
change in galvanometer deflection will depend upon the cu
flowing in the arm BD. This will further depend upo
resistance of the arm BD. *Smaller it is, better would b
adjustment.*

6. It is essential to connect a high resistance in series
the cell. If it is not done so, heavy currents will pass thr
the galvanometer. This may damage it. Or potential divider
be used.

7. If possible a P. O. box dial pattern should be prefe
because in it, uncertain contact resistances will be consider
reduced.

*8. In order that the bridge may be most sensitive
resistances in all the four arms of the bridge should be alm
of the same order.*

*9. If a suspended coil type of galvanometer is taken
should be properly levelled so that the coil moves freely betwe
the two pole pieces of the magnet.*

Criticism—*This method yields quite satisfactory resu
if the experiment is performed carefully.* When the ratio P :
is made as 1000 : 10, the *resistances in the four arms of t
bridge differ too much from each other*; consequently th
bridge will become insensitive.

Thus, as the resistance R_1 is very large, the current in the circuit almost remains unaffected *by putting a resistance R in parallel to G*. Let R be the value of the resistance put across G, so that the deflection in the latter is *reduced to half of its previous value*. Evidently therefore, half of the current *i* flows through G and half of it through R. As they are in parallel,

$$G = R \qquad \ldots \qquad \ldots \qquad \text{(vi)}$$

Method:—1. Make neat and tight connections as shown in the figure. Put the given galvanometer G in series with an accumulator through a high resistance R_1 and the key K_1. Put a resistance box R across the two terminals of the galvanometer through a key K_2.

2. Close K_1 and adjust R_1, so that a *convenient deflection* is obtained in the galvanometer (it should be more than half of the scale divisions provided in the instrument). R_1 should be taken of the order of 10,000 ohm. Let the deflection be = *n* divisions.

3. Close K_2 and adjust the value of R, so that the deflection in the galvanometer is reduced to half of its previous value i. e. it becomes = *n*/2 divisions. It gives the resistance of the galvanometer.

4. Change the value of R_1 and take a number of sets.

5 Determine G from each set, and then find out its mean.

Observations:—

S. N.	Deflection in the galvanometer in the beginning when K_2 is open in divisions	Resistance required for half of the previous deflection R *in ohm*.
1.		
2.		
3.		
4.		
5.		

EXPERIMENT NO. [illegible]

Experiment: To [illegible] the resistance of a galvanometer by [illegible]

Apparatus — An accumulator, the given galvanometer, [illegible] resistance box containing resistance [illegible], a resistance box of the range of [illegible], connecting wires etc.

Theory —

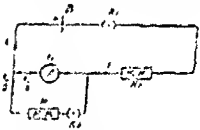


Fig. 1

For a convenient deflection in the galvanometer, let i be the current flowing through it and the high resistance R_1, then, we have,

$$i = \frac{E}{G+R_1} \quad \ldots \quad \ldots \quad \text{(i)}$$

where E is the e. m. f. of the accumulator, G the resistance of the given galvanometer and R_1 the value of the high resistance put in series with the galvanometer. If $R_1 >> G$, equation (i) becomes,

$$i = \frac{E}{R_1} \quad \ldots \quad \ldots \quad \text{(ii)}$$

Let the new current in the circuit be i_1. When a resistance is put in parallel to the galvanometer, then,

$$i_1 = \frac{E}{\frac{GR}{G+R} + R_1} \quad \ldots \quad \ldots \quad \text{(iii)}$$

Again if $R_1 >> G$ and R

$$i_1 = \frac{E}{R_1} \quad \ldots \quad \ldots \quad \text{(iv)}$$

$$i = i_1 \quad \text{(v)}$$

EXPERIMENT No. 34

Experiment:—To determine the theormo-E. M. F. of a copper - iron couple; and then to draw a graph between the thermo - E. M. F. generated and the temperature of the hot junction, keeping the temperature of the cold junction constant.

Apparatus:—A potentiometer, an accumulator, a standard cell (cadmium cell is preferable, if it is not available, freshly prepared Daniell cell should be used), two resistance boxes of the range of 0-10,000 ohms, a rheostat, a weston type galvanometer, a shunt wire, a plug key, a three way key, copper iron thermo-couple, beakers, a test tube containing mercury, sand bath, thermometer, burner, connecting wires etc.

Description of the apparatus:—A copper iron thermo-couple consists of an iron wire, each end of which is connected to a copper wire. The free ends of the copper wires are connected to a circuit containing a galvanometer. One junction of the couple is immersed in *a cold bath made* by taking cold water or ice in a beaker, while the other end is put in *a hot bath* prepared by taking mercury in a test tube heated on a sand bath When *temperature difference is set up between the two junctions,* current begins to flow from copper to iron at the hot junction and the galvanometer gives deflection. The current generated is known as *thermo-electric current.*

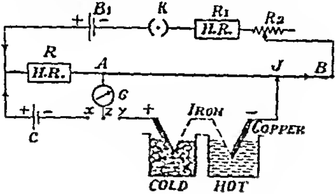


Fig. 1.

Calculations

$G = S - ...$

Result—The resistance of the galvanometer = ... ohms.

Precautions and sources of error—1. The high resistance R should be of the order of 10,000 ohms, otherwise the deflection in the galvanometer will go off the scale and the instrument may be damaged. ... only when ... is very large.

2. The key should be closed only when taking observations.

3. The deflection obtained in the galvanometer should always be more than half of the scale provided, because more is the deflection, lesser will be the mistake made in reading it.

Criticism—Though this method is not very accurate, it gives fairly satisfactory results. It is very convenient, and can be performed in a comparatively lesser time.

Oral Questions—1. *See questions on electricity* ? 2. *See experiments 11 and 12*. 3. Is it a good method of determining resistance ? 4. Why is it called half deflection method ? 5. How do we presume that the current remains the same, even after connecting a resistance in parallel to the galvanometer ? 6. Why a high resistance should be connected in series with the galvanometer ? 7. Can you use a primary cell instead of an accumulator ?

2. Connect a high resistance R in series with the potentiometer wire AB. It should be near about 1000 ohms depending upon the resistance of the potentiometer wire. Put this combination in series with an accumulator B_1, a high resistance R_1 (of the same order as that of R) and a rheostat R_2 through a plug key K. The current in the potentiometer wire *should enter from the terminal* A, as shown in Fig. 1 so that A becomes the +ve terminal of the wire.

3. Join the +ve pole of a standard cell (or a freshly prepared Daniell cell) to the higher potential terminal of the resistance box R, and the −ve pole to the terminal x of a three way key. Connect the terminal z of the key to the end A of the potentiometer wire through a galvanometer G. Join the free end of the copper wire of the cold junction to the third terminal y of the key, and free end of the copper wire of the hot junction to the jockey J.

4. Close K, and join x to z (by putting the plug between x and z). Introduce a resistance of nearly 1000 ohm in (R. B) R, and *nearly an equal resistance in* R_1. Now by adjusting R_1 and R_2, balance the e. m. f. of the cell against the p. d existing between the two terminals of R. It can be done by obtaining no deflection in the galvanometer. While making final adjustment remove the shunt from the galvanometer. (Now the p. d. across R = the e. m. f. E of the cell).

5. Disconnect x from z and switch off the current in the potentiometer circuit, by taking out the plug in key K.

Put the cold junction in ice. If ice is not available put it in a beaker containing cold water. Note down its temperature by a thermometer reading up to 1/5°C. It gives t_1, the temperature of the cold junction. Now put the hot junction in mercury contained in a copper test tube. Put the latter in a sand bath heated by a burner. Again determine the temperature of the hot junction by a thermometer reading up to 1/5°C. It gives t_2. If sand bath is not available, take glycerine or some such oil (*possessing high boiling point*) in a beaker, and put the hot junction in it. Heat the oil, stir it well, and determine its temperature by a thermometer put in it.

Theory—The connections are self explanatory. For a temperature difference of 100°C between the two junctions the thermo-e. m. f. generated *is of the order of 0.0013 volt i. e. 1.3 milli-volt. It is fairly small* and to measure such small potential differences, the potential gradient along the potentiometer wire *should be of the order of a micro-volt.* To obtain such a low potential gradient, a high resistance R (of the order of 1000 ohm) is connected in series with the potentiometer wire AB. This combination *is then put in series with an accumulator* B_1, a high resistance R_1, and a rheostat R_2. Now a standard cell or a Daniell cell is balanced across the two terminals of the resistance R by adjusting R_1 and R_2. Let i be the current *flowing through the potentiometer circuit (i. e. through* R and AB); then we have,

$$E = i\,R \qquad \dots \qquad \dots \qquad (i)$$

Now keeping i constant, the thermo-e. m. f. e generated *in the couple is balanced across the potentiometer wire. Let* its balancing length be l, and r be the resistance of the length l of the wire. Let ρ be the resistance of the wire per unit length Then, applying Ohm's law we get,

$$e = ir = i.\,\rho.\,l. \qquad \dots \qquad (ii)$$

∴ From eqns, (i) and (ii) we get,

$$e = \frac{E}{R}\,\rho l \qquad \dots \qquad (iii)$$

Let R_3 and L be respectively the resistance and total length AB of the potentiometer wire, then

$$\rho = \frac{R_3}{L} \qquad \dots \qquad \dots \qquad (iv)$$

$$\text{or} \qquad e = \frac{E}{R}\cdot\frac{R_3}{L}\cdot l \qquad \dots \qquad (v)$$

Knowing all the symbols in equation (v) e can be calculated. Knowing e at various temperatures, a graph is drawn between the thermo-e. m. f. *generated and the difference of temperature between the two junctions.* From the graph *neutral point* i. e. the temperature at which e is maximum is determined.

Method:—1. *To start with, connect the potentiometer* wire AB to the unknown resistance arm of a post office box, and determine its resistance *(See expt. No. 32). It gives R_3. Find* out its total *length* L *and determine* resistance per unit length

$$\rho = \frac{R_3}{}$$

(4) For thermo-e.m.f. generated in the couple :—

S. N.	High Resistance R in ohm.	Temperature in °C		Diff. in temp. between two junctions $t=(t_2-t_1)$ in °C	Balancing length of the potentiometer wire when temperature is		Mean length (l) in cms $\frac{P+Q}{2}$	Thermo-e.m.f. generated in micro-volts $e=\frac{E}{R}\cdot\frac{R_1}{L}\cdot l$
		Hot junction (t_2)	cold junction (t_1)		increasing (in cm.) (P)	decreasing (in cm.) (Q)		
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

6. When the temperature of the hot junction rises nearly by 20° above that of the cold junction, connect x to y and close the key K. The resistance R, R_1 and R_2 should not be disturbed so that the current in the potentiometer wire may remain the same. *Now due to the generation of thermo-e.m.f.* (e) galvanometer will give some deflection. By sliding the jockey J balance this e.m.f. (e) on the potentiometer wire by obtaining *no deflection in the galvanometer. Remove shunt* while making final adjustment. The temperature of the hot junction should be so regulated that it remains almost constant when balance point is obtained. Determine this balancing length. It gives l. Read the thermometer attached to the hot junction when the balance point is obtained. It gives t_1.

7. Now gradually increase the temerature of the hot junction. *After every 20° rise in* temperature obtain the balancing length as described above, till the hot junction is heated to a temperature of nearly 350°C, if it is possible.

8. Put off the burner, and let the hot junction cool. Again determine the balancing lengths of the wire for the same temperature (as determined above) while the temperature is falling. Thus, for the same temperature of the hot junction, two readings for l can be obtained. Determine the mean of the two readings.

9. *Periodically check the temperature of the cold* junction. It should remain constant at t_0°C.

10. Knowing E, l and R, calculate the value of e, the thermo-e.m.f. generated at different temperatures of the hot junction.

11. Determine the *difference* between the temperatures of the hot and the cold junction (t) for every reading. Plot a graph between this difference of temperatures between the two junctions (t) *and the corresponding thermo-e.m.f. generated* (e). It will come out to be a parabola.

12. From the graph find out the neutral temperature corresponding to which the thermo-e.m.f. generated in the couple is *maximum.*

Observations:—

(1) Resistance *of the potentiometer wire* AB (R_1)=...ohm.

(2) Length of the potentiometer wire AB (L) =...cm.

Oral Questions:—1. What is a thermo-couple, and how thermo-currents are produced ? 2. What is the direction of the current in a thermo-couple ? On what factors does it depend ? 3. What is neutral temperature and how is it determined ? 4. Define temperature of inversion ? Does it depend upon the temperature of the cold junction ? 5. What is a thermo pile and what are its uses ? 6 Is thermo-e.m.f, a reversible process if, yes, how ? 7 Which couple generate the maximum thermo-e.m f. for the same difference of temperature between its two junctions. 8. What is the order of the magnitude of the thermo e.m.f. developed in an iron-copper, thermo-couple ? 9. How is such a small e.m.f. measured by the potentiometer ? 10. Why such high resistances are put in series, with the potentiometer wire AB. ? 11. Which end of the thermo-couple should be connected to the terminal A of the potentiometer wire and why ?

Calculations:—

1. The resistance per unit length of the potentiometer wire ρ = ... ohm.

2. Calculate the thermo-e.m.f. generated (e) by each observation *from formula (iii)* or *(v)* and then draw a *graph* between the difference of temperaturee between the two junctions and *the corresponding thermo-e.m.f.* generated.

Result:—The graph is in the from of a parabola. The temperature at which the thermo-e.m.f. is maxiumum i.e. the neutral tempetature for iron-copper couple=...°C.

Precautions and sources of error:—

1. *See expts. 16, 17, 18.*

2. The accumulator B, should be fully charged and *must possess a fairly large capacity, so that the e.m.f. in the potentiometer circuit may remain constant.* To keep this e.m.f. steady *a key should always be provided* in the potentiometer circuit, and current should be drawn only when taking observation.

3 The jockey should be pressed only for a small time. It should not be moved on the wire pressed, otherwise the uniformity of the wire would be spoiled.

4. The thermo-e.m.f. generated is very small, and therefore, the p. d across the potentiometer wire *AB should not be more than 1 millivolt, so that the potential gradient becomes one micro-volt.*

5. A very high sensitive galvanometer should be employed to determine the balance point. A moving coil suspended type of galvanometer with lamp and scale arrangement will give better result.

6. In the thermo-couple the two dis-similer metals should be *in contact, with each other only at the junction.*

7. Higher potential terminal of the thermo-couple should be connected *to the end A of the potentiometer wire.*

8. While determining balance pointe the current i in the potentiometer wire should remain constant, otherwise the calibration will go wrong.

Criticism:—The method gives feirly good result. However, the accuracy will largely depend upon the constancy of e.m.f. of the accumulator, and the exact *knowledge of the* e.m.f. of the standard cell or the Daniell cell, used to calibrate the potentiometer wire. The main *source of error* in this experiment is that as the wire used is very long, it cannot be of uniform thickness *through out its length,* hence the potential gradient will not remain constant. Thus, to avoid this error Cromption's *potentiometer* is preferred.

maximum value of the alternating e.m.f. developed across the two ends of the choke coil C, and I_0 be the maximum value of the alternating current flowing through it. Then, we have,

$$\therefore \quad I_0 = \frac{Eo}{\sqrt{R^2 + \omega^2 L^2}} \quad \ldots \quad (i)$$

Where, L and R are respectively the inductance and the resistance of the coil C and $\omega = 2\pi n$, where n is the frequency of the A. C.

$$\therefore \quad Io = \frac{Eo}{\sqrt{R^2 + 4\pi^2 n^2 L^2}} \quad \ldots \quad (ii)$$

$\sqrt{R^2 + 4\pi^2 n^2 L^2}$ is known as the impedence of the coil. If the impedence is denoted by Z,

$$Z = \sqrt{R^2 + 4\pi^2 n^2 L^2} \quad \ldots \quad (iii)$$

$$\text{or} \quad Z = Eo/Io \quad \ldots \quad \ldots \quad (iv)$$

But as the A. C. instruments only read virtual volts and virtual amperes,

$$Z = \frac{Eo/\sqrt{2}}{Io/\sqrt{2}} = \frac{\text{Virtual E. M. F.}}{\text{Virtual current}} = \frac{E}{I} \quad (v)$$

Where E and I are respectively the e.m.f. and current measured by the A. C. voltmeter, and the A. C. ammeter. If R is known, knowing Z, the value of L can be calculated from equation (iii).

Method:—1 Connect the primary coil P to the A. C. mains. Put the choke coil C in series with the secondary coil (S) of the step-down transformer through an A. C. ammeter A and a high resistance rheostat, R_h. Connect the A. C. voltmeter across the two terminals of the choke coil.

2. Switch on the A. C. mains, and adjust the value of R_h to obtain a potential difference of nearly 5 to 10 volts across the two terminals of the choke coil C.

3. Read the voltmeter. It gives E, the value of the virtual e.m.f. acting across the coil. Similarly read the ammeter. It gives I, the value of the virtual current flowing through C. It completes one set of readings for E and I.

4. Change the value of the resistance R_h, and repeat the above procedure. In this way take atleast 7 to 8 *different sets* of readings.

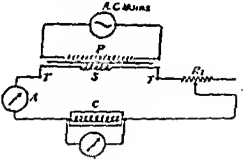
5. Calculate the value of the impedence Z by each set and then determine its mean value.

[illegible] impedance of a [illegible] A. C. mains and finding the resistance of the choke coil [illegible] inductance.

Apparatus—A. C. mains, a step down transformer, the choke coil, a high variable resistance in the form of a rheostat, an A. C. voltmeter, an A. C. ammeter, connecting flex wire, etc.

Description of the apparatus—Choke coil. It consists of insulated copper wires wound over a soft iron core and is laminated. It possesses very little or practically zero resistance, but a high inductance.

Step-down transformer—It is a device for converting high A. C. voltage at low current strength to low A. C. voltage at high current strength. It consists of two coils, a primary (P) and a secondary (S) wound upon an iron core. The primary contains a large number of insulated copper wires and is connected to the A. C. mains. In a step-down transformer, the secondary has a fewer turns, and is connected to the circuit in which the A. C of lower voltage is to be fed. For description of A. C. voltmeter and A. C. ammeter see notes on electricity in the beginning of the section. *Primary and secondary are insulated from each other.*



Criticism:—The method gives fairly good results. A large number of sets should be taken for E and I to get the correct value of the impedence Z.

Oral Questions:—1. What is an A. C. current and how does it differ from a D.C. current ? 2. What is a transformer ? 3. How does it step up or step down the incoming voltage ? 4. Why the coils are wound over a soft iron core ? 5. How is the A. C. e. m. f. and current measured ? 6. What is difference between the A. C. measuring instruments and D. C. measuring instruments ? 7. Why the divisions on the scale are crowded for the lower values in the A. C. measuring instruments ? 3. What do you understand by the impedence of an A. C. circuit, what are the units in which it is measured ? 9. Define reactance and give the relation between impedence, reactance and ohmic resistance. 10. What is the function of a choke coil in an A.C. circuit ? 11. What are virtual volts and virtual amperes ? 12. Do tha A C. instruments measure the virtual volts and amperes or actual volts and amperes ? 13. Can these A. C. instruments be used to measure D.C. voltage and current? 14. Why a high resistance rheostat R_1 included in the circuit ? 15 Does this stepping down of the incoming voltage alter the frequency ?

6. Switch off the current, put the choke coil in the unknown resistance arm of a P. O. box, and determine the *resistance of the coil by the procedure described in experiment* No. 32. It gives the value of R.

7. Knowing Z, R and n determine the inductance L of the coil by the equation (iii).

Observations:—

S. N.	E. M. F. E in volts	Current I in amp.	*Impedence* Z=E/I in volts	*Resistance of the choke coil R in ohms*	Inductance of the choke coil L in henries
1					
2					
3					
4					
5					
6					

Calculations:—Calculate the impedence Z by the formula Z=E/I by each observation and determine the mean value of Z. Knowing Z and R calculate L by the formula,

$$Z^2 = 4\pi^2 n^2 L^2 + R^2$$

$$\text{or} \quad L^2 = \frac{Z^2 - R^2}{4\pi^2 n^2}$$

Result:—

(1) *The impedence of the given choke coil = ...ohm.*

(2) The inductance of the coil = ...*Henries.*

Precautions and sources of error:—1. Only the secondary coil of the transformer should be connected in the circuit. If the connections are done the other way, e. m. f. in the circuit will enormously increase.

2 Ammeter should be connected in series, while the voltmeter should be put in parallel to the choke coil.

3. *In the A. C. measuring instruments, the divisions on the scale are not uniformly spaced. They are crowded towards the lower values, and expanded at the higher values. Therefore, to read them more accurately higher values of current and* p. d. *should be taken.*

vibrate in loops as described in Melde's experiment. If the length of the string is adjusted to obtain well defined nodes and antinodes, the string will be in resonance with the vibrator i. e. the frequency of vibration of the string will be the same as that of the vibrator, which itself is vibrating with the frequency of A. C. mains Let this resonant length of one loop of the cord be l, and n be its frequency of vibration, then we have,

$$n = \frac{1}{2l}\sqrt{T/m} \quad \ldots \quad (1)$$

Thus, knowing l, T and m, n can be calculated.

Method:—Switch on the current and adjust the length of the rod CD so that it is in resonance with the A. C. supply. It can be obtained by getting the maximum amplitude of vibration of the free end.

2. Weigh the pan in which the weights are to be put. Take a light string and tie its one end to the vibrator, and the other end to the pan passing over the pulley Put some weights in the pan (say 1 to 2 gm.) so that tension is applied and the string begins to vibrate. As described in Melde's experiment loops will be formed on the string.

3. By shifting the vibrator forwards or backwards change the length of the string so that the nodes and antinodes are rendered sharp and well defined. (Under these conditions the string will be in resonance with the vibrator).

4. Leaving out the two extreme loops, determine the length of the string between the rest of the intervening loops. Let it be L. Count the number of intervening loops. Let it be p, then L/p will be the length between two consecutive nodes.

5. Keep tension constant, change the length of the string and the number of loops and similarly obtain resonance. In this way for the same tension obtain atleast three sets. Find out the value of l in each case, and then determine its mean value.

6. Add the weight of the pan to the weights put in the pan and multiply it by g to get the total tension (T) applied to the string.

7. Weigh the string, and find out its mass per unit length (m),

8. Knowing l, T and m calculate n. It completes one set.

9. Now change the tension for two or three times, and similarly obtain the values for l, T and m for each set.

10. Calculate the value of n from each set, and then find its mean.

EXPERIMENT No. 38

Experiment:—To determine the frequency of A. [illegible] mains with the halp of an electtical vibrator,

Apparatue : Electtical vibrator, string, pulley pan, w[illegible] box, table lamp etc.

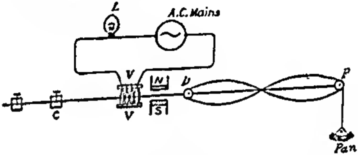


Fig. 1.

Description of the apparatus:—The electrical vibrato[illegible] consists of a solenoid VV through which passes a thin ste[illegible] wire CD. One end of the wire is clamped at C, while the fre[illegible] end D passes through the two pole pieces of a permanent magne[illegible] NS and carries a hook (or a hole). A string is tied at th[illegible] free end. The other end of the string passes over a pulley P an[illegible] carries a pan in which weights can be put. The two ends of th[illegible] solenoid wire are connected to the A. C. mains whose frequenc[illegible] is to be determined through a 100 watt lamp L.

Theory:—When a current is allowed to pass through th[illegible] solenoid the iron rod is magnetised longitudinally. Its polarit[illegible] reverses with the change of sign of the current. Due to th[illegible] interaction between field of the wire and field of the permanent magnet, the iron wire begins to vibrate with the frequency o[illegible] A. C. supply. The length of the wire CD is adjusted to get th[illegible] maximum amplitude of the free end.

Let the mass per unit length of the string connected t[illegible] the vibrator be m. If it is stretched by a tension T (which can be obtained by putting weights in the pan) it will begin to

Calculations:—Calculate n by the formula,

$$n = \frac{1}{2l}\sqrt{\frac{T}{m}}$$

for each set, and then determine the mean value of n i. e. the frequency of the A C. mains.

Result:—Frequency of the A. C. mains (n) = ... V./S.

Precautions and sources of error:—1. The string used must possess fairly a constant mass per unit length, hence a fishing cord is more satisfactory than an ordinary thread.

2. To start with, it should be carefully seen that the iron rod is in resonance with the A. C. supply. If it is so the free end of the rod will vibrate with maximum amplitude.

3. The pulley should be frictionless, otherwise the computed tension will not be the actual tension applied.

4. Nodes formed on the string must be sharp and well defined. As the first and the last node cannot be accurately located, the two extreme loops should not be taken in to account while finding l.

5. The hanging pan must be steady while the final reading is taken.

Criticism:—See Melde's experiment. The greatest error is involved in measuring the length of the loops To get better results, the number of loops taken should be large.

Oral questions.—1 See Melde's experiment. 2 What do you mean by A. C. mains and its frequency ? 3. How do you determine it by this method ? 4 Describe an electrical vibrator. 5. What are the functions of the solenoid and the permanent magnet ? ✓6. Why a lamp is employed in series with the mains ? 7. What is the frequency of the A C. Supply in your city ? 8. Why the length of the rod is adjusted in the beginning ? 9 Is there any other method of determining this frequency.—

ngth of the string = ... cm.
ass of the string = ... gm.
Mass per unit length of the string = ... gm.
cceleration due to gravity g = ... cm/sec^2
n

Wt. pan (W_1) in gm.	wts. placed on the pan (W_2) in gm.	Tension $T=(W_1+W_2)g$ in dynes,	S.N.	No. of loops (p)	Length of the string for p loops (L)	Length of the string for one loop (l)	Frequency $n=\frac{1}{2l}\sqrt{\frac{T}{m}}$
			1 2 3				
			1 2 3				
			1 2 3				

change in anode voltage required to cause a certain small change in anode current to the change in grid voltage required to cause the same change in anode current. See fig 1. Three curves are drawn between grid potential and anode current at three fixed anode voltages viz. 60, 80 and 100 volts. It is clear that a change in anode current by an amount AB can be done either by changing the grid potential from C to B at plate potential of 80 V or by changing the anode potential from 60V to 80 V at grid potential of B. Thus if μ represents the amplification factor,

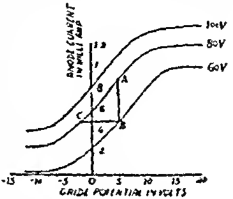


Fig. 1

$$\mu = \frac{\delta v_p}{\delta v_g}$$

$$\mu = \frac{80\,V - 60\,V}{G_1 - G_2} \quad \dots \quad (i)$$

Here $G_1 - G_2$ represent grid potentials at B and C respectively

This factor has no units and its value must be greater than 1 and sometimes is higher than 100

(ii) Grid plate transconductance or mutual conductance: It is defined as the rate of change of anode current with grid potential, keeping the plate voltage constant.

$$\text{or} \quad g_m = \frac{\delta i_p}{\delta v_g} \quad — \quad — \quad — \quad (ii)$$

In other words it is defined as the slope of the anode current and grid potential curve. From figure 1,

$$g_m = \frac{i_1 - i_2}{G_1 - G_2} \dots (iii)$$ Where i_1 and i_2 respectively is the anode current at A & B

It is measured in mhos.

EXPERIMENT No. 37

Experiment:—To draw characteristic curves of a given triode valve and determine its constants.

Apparatus:—A triode valve fitted properly with a socket, a source of low tension for filament usually a 2 volt battery or a L. T. transformer, a grid bias battery capable of giving say 30 volts with a potentiometer arrangement, a high tension battery giving upto say 250 volts or any other source like a rectifier, a milliammeter, two voltmeters - one reading upto 30 V. and the other upto 250 V., rheostats, plug keys etc.

Description of Apparatus:—As the name suggests, usually there are three electrodes—cathode, grid and anode in a triode valve. Cathode is either directly or indirectly heated to give a source of electrons.

Anode is kept positive with respect to the cathode and as a result it gives anode or plate current.

This plate current is controlled by applying suitable potentials to the grid electrode-which lies nearer to the cathode. Its construction is such that it itself attracts a negligible fraction of the current but due to its nearness affects very significantly the plate current.

There are various types of triode valves and as such before using it, correct connections with various terminals of the sockets must be understood. Also remember, that filament of the valve is a very sensitive part and therefore its correct p. d. and current capacity must be known before its use.

Theory:—*As we have already seen, there are three independent* variables viz. cathode temperature, grid potential, and plate potential. On these depend two variables viz. plate current and grid current. *By varying one of these independent variables, the* dependence of these two dependent variables can be studied. These *variation* curves *are* called characteristic curves. The most important characteristic *curve is that which is drawn* between grid potential and plate current at a constant plate potential and *filament current.*

Following *are the three* constants of a triode valve. They depend on its *geometry.*

factor—It is defi of the

Mark these two **terminals of H. T.** carefully and note which is +ve and which is −ve terminal. As shown in diagram the +ve terminal is connected through a milliammeter to the plate terminal of the valve and the −ve terminal is connected to the −ve terminal of L. T. which is connected to filament.

Between the two terminals of the H. T. is also connected in parallel a high range D.C. voltmeter.

(c) *Grid circuit:*—The grid bias is supplied either by a lead accumulator or a dry cell. In series with it, is arranged a potentiometric circuit through a plug key. As we are required to use both +ve and −ve bias, the connections made are slightly unusual.

In series with the battery, is connected a high resistance (rheostat) and a plug key. The two fixed terminals of the rheostat must be used. Now connect the mid point of the battery to the −ve terminal of the L. T. of filament and the variable contact of the rheostat is connected to the grid terminal of the valve. In parallel with these two points is connected such a voltmeter whose zero lies in the centre of the scale and is capable of reading upto say 15 volts on either side.

The connections are now complete.

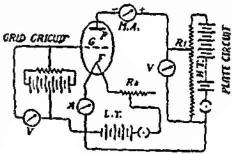


Fig. 2

4. Having satisfied that the connections are complete, insert the filament circuit key and adjust the current with the help of rheostat to the specified value.

5. Now insert the plate circuit key and adjust the rheostat till the reading in voltmeter is say 60 volts. Thus, a +ve potential is applied between the filament and the plate.

6. Then insert the grid circuit key and adjust the sliding contact of rheostat till the voltmeter reads say −12 volts. Now the grid is −ve with respect to the filament and a p. d. of 12 volts exists between them.

7. Under the above conditions, note the current in milliammeter. This gives plate current at a plate potential of 60 V. and grid bias of −12 V.

(iii) Plate resistance (r_p)—It is the interal resistance of the valve offered to the flow of current in between the filament and the plate. It is defined as the ratio of change of anode potential to the change in anode current caused at a fixed grid potential.

$$\text{Thus } r_p = \frac{\delta v_a}{\delta i_a}$$

$$= \frac{80\ \text{V} - 60\ \text{V}}{i_a - i_b} \quad \ldots \quad \text{(iv)}$$

$$= \frac{\mu}{g_m} \quad \ldots \quad \ldots \quad \text{(v)}$$

Method:—Generally the arrangement of apparatus varie from place to place and the *maintenance* of potentials depend on the type of triode valve. So the method given below doe not mention anything in particular but describes it in a genera way.

1. Before making connections it is assumed that th triode valve is properly fixed in its socket and the variou terminals e. g. filament, plate etc. are clearly and correctl indicated.

2 Ascertain whether the cathode of the given triod is directly or indirectly heated one. Find out the require potential and the current for cathode heating. Violation of thi precaution might fuse the valve.

3. Normally for this experiment three separate circuit plate, grid and filament are required.

(a) Filament Circuit:—As shown in figure 2 connec the two filament terminals to the low tension (L. T.) batter (say giving 2 volts or 6 volts depending on the valve) through fine rheostat and an ammeter. It is advisable to insert a plu key also. Before inserting the plug see, that the rheostat i so adjusted that it offers maximum resistance. Gradually slid it till the ammeter registers proper current for the given valve.

(b) Plate circuit—High tension (H. T.) is needed fo this circuit. Usually a set of dry cells or a rectifier unit is use for this purpose. It is assumed here that a student is supplie with a source of H. T. Usually a potentiometric arrangement i also incorporated in the unit and a student is not required t make it. One terminal on this potentiometer is fixed while th the other can be varied to get different values of H. T.

From the graph find the change in current corresponding to BA i. e. ($i_a - i_b$) and the change in grid potential corresponding to B and C i. $G_b - G_c$.

Now with the help of equations (i), (iii) and (iv) find μ, g_m and r_p .

These calculations can be repeated by choosing B point on enother curve also.

The point B is taken on 60 V curve while C and A on 80 V curve.

$\therefore$ difference in plate potential$= 80\text{ V} - 60\text{ V} = 20$ volts.

Change in plate current $i_a - i_b = \ldots$ milli-amp. $= \ldots$ amp.

change in grid potentials $G_b - G_c$ $= \ldots$ volts.

$$\therefore \mu = \frac{80\text{V} - 60\text{ V}}{G_b - G_c} =$$

$$g_m = \frac{i_a - i_b}{G_b - G_c} = \ldots \text{ mhos}$$

$$r_p = \frac{\mu}{g_m} = \frac{80\text{ V} - 60\text{ V}}{i_a - i_b} = \ldots \text{ ohms}$$

Result:—$\mu = \ldots$, $g_m = \ldots$ mhos , r_p $= \ldots$ ohms.

Sources of error and precautions:—1 The charecteristics of the valve must be known before use and the specifications given must not be exceeded.

The filament heating current must be maintained absolutely constant. To echieve this a sensitive ammeter and a proper rheostat must be used.

3. The electrons flow from filament to the plete inside the valve. As such the conventional direction of current is from plate to filament inside the valve. Therefore, the —ve of the milliammeter must be connected to the plate.

Normally the grid potential with respect to filament should not exceed 20 volts. Otherwise there might be excessive mechanical strain in between the two and the filament might give way.

5. If the centre of the grid bias battery is not connected to the —ve of L. T. battery, the connections will have to be changed for application of +ve and —ve grid bias. In this case simply by varying the variable rheostat, contact is achieved. Remember that use of zero centred voltmeter is essential for this purpose.

8 Now with the help of grid circuit rheostat increase the grid bias in steps of 2 volts e.g. −10V, −8V etc. upto +12 Volt and keeping plate potential constant at 60 V read the plate current with the help of milliammeter. Remember that the filament current must also be kept constant. This completes one set.

9 Keeping the filament current constant, change the plate potential to 80 V and then to 100 V. Each time repeat the above set by noting plate current at various grid bias.

10. Draw a graph between grid bias as abscissa and plate current as ordinate. You will get three such curves at 60 V, 80 V, and 100 V respectively.

Observations—Specifications of Triode valve, if any. Valve Number :

Filament heating current .

Maximum plate potential .

S. N.	Grid potential in volts	*Plate current in milli-amperes when plate potential is equal to*		
		60 V	*80 V*	*100 V*
1	−12 V			
2	−10 V			
3				
4				
5				
6				
7				
8				
9				
10				
11				
12	+10 V			
13	+12 V			

Calculations:—you will get the curves as shown in Fig. 1. The peculiarity of the curves is that their lower and upper portions are curved while the middle portion is straight.

Approximately in the middle of the straight portion on the curve for say 60 V, choose a point B. Draw two straight lines BC and BA parallel to X and Y axis respectively and intersecting the next higher curves say of 80 V at C and A.

From the graph find the change in current corresponding to BA i. e. ($i_a - i_b$) and the change in grid potential corresponding to B and C i. $G_b - G_c$.

Now with the help of equations (i), (iii) and (iv) find μ, g_m and r_p .

These calculations can be repeated by choosing B point on another curve also.

The point B is taken on 60 V curve while C and A on 80 V curve.

$\therefore$ difference in plate potential $= 80\text{ V} - 60\text{ V} = 20$ volts.

Change in plate current $i_a - i_b =$ ... milli-amp. $=$ ... amp.

change in grid potentials $G_b - G_c$ $=$ ... volts.

$$\therefore \mu = \frac{80\text{V} - 60\text{ V}}{G_b - G_c} =$$

$$g_m = \frac{i_a - i_b}{G_b - G_c} = \text{... mhos}$$

$$r_p = \frac{\mu}{g_m} = \frac{80\text{ V} - 60\text{ V}}{i_a - i_b} = \text{... ohms}$$

Result:—$\mu =$ ... ; $g_m =$ ... mhos ; r_p $=$ ... ohms.

Sources of error and precautions:—1. The characteristics of the valve must be known before use and the specifications

6. It is generally observed that the plate potential is of [illegible] be applied and bias. The plate potential for one set of observations must be kept constant.

7. For calculations, only straight portion of the characteristic curves must be used.

8. Whenever you are not working, remove the plugs from the keys. This will avoid excessive heating and save the batteries.

Oral questions—1 *Describe a triode valve.* 2 Why is it called a valve ? 3 Of what materials is the filament made, and why ? 4 What are the different arrangements employed for heating the filaments ? Why currents, more than specified should not be allowed to flow through the filament ? 6. What is the function of a grid, and how the grid bias is made +ve or −ve with respect to the filament ? 7 How is plate potential applied ? 8 Describe the construction, principle and working of a rectifier. 9. What are the characteristic curves of a triode and how are they drawn ? 10. Define amplification factor, mutual conductance and plate resistance and give their units. 11. What is the relation between these three triode constants ? 12. Why the filament current and plate potential kept constant while taking one set of observations. 13. Why the potential difference between the grid and filament should not exceed 15 to 20 volts. 13. What are the uses of a triode valve ?

$$K = \frac{T}{2\pi} \cdot \frac{c}{\phi} \quad \ldots \quad \ldots \quad \text{(vii)}$$

where, T is its periodic time, and ϕ the steady deflection produced in it due to the flow of current c through it.

Knowing all the quantities mentioned in eqn. (vii) K can be calculated.

Method:—This experiment is generally set in a dark room, and the throw of the galvanometer is measured by lamp and scale arrangement.

Setting of the galvanometer:—

1. Usually, you would find the galvanometer in more or less a set position. Assuming that, it is correctly set, following procedure is recommended:—

Study the given galvanometer very carefully and find out what type of clamping arrangement is provided in it.

2 Release its coil with the help of the clamping arrangement.

3. With the help of a spirit level, level it properly. usually it stands on three adjustable legs.

4. Opposite the galvanometer, at a distance of one meter or so, keep your lamp and scale arrangement.

5. See carefully whether the lamp is to be lighted by a 6 volt line or a 220 volt line. Accordingly light it.

6. Adjust the height of the lamp and the scale, so that a spot of light after getting reflected from the galvanometer falls on the scale.

7. Focus it by adjusting the lens fitted in the lamp. It is more convenient to first catch the spot of light on an opaque screen near the galvanometer, and then move it till we reach the scale. This setting always needs some practice. As far as possible the spot should lie at the zero of the scale.

8. Now look carefully towards the galvanometer coil. See that it hangs symmetrically round the soft iron core without touching its pole pieces.

9. Slightly blow in to the galvanometer or gently touch its terminals so that its coil is slightly deflected and begins to oscillate. Now see that the coil oscillates *freely* and spot of light returns to its zero and initial position. Thus the galvanometer is ready and set for the experiment.

Very small currents should be allowed to enter ballistic galvanometer, because it is very sensitive. It is achieve in practice by making a potential-divider arrangement as show in fig. 1.

Theory:—The connections are self explanatory. Tw resistance boxes are connected in series with an accumulato A high resistance R_2 (nearly of the order of 100 to 500 ohm is introduced in one of them; while in the other a sma resistance R_1 (of the order of 1 to 10 ohm.) is introduce The ballistic galvanometer B. G. is connected in parallel to th small resistance R_1 through a fairly high resistance R (of th order of 10,000 ohm.)

Let E be the e. m f. of the accumulator, and i be th current flowing through the resistance R_1 and R_2, then,

$$i = \frac{E}{R_1 + R_2} \quad \dots \quad \dots \quad \text{(i)}$$

If V is the potential difference across the terminal of R_1,

$$V = R_1 i = \frac{R_1 E}{R_1 + R_2} \quad \dots \quad \text{(ii)}$$

This p. d. drives the current through the ballistic galvanometer. Let c be the current flowing through the galvanometer and the high resistance R, then, we have,

$$c = \frac{V}{R+G} \quad \dots \quad \dots \quad \text{(iii)}$$ where G is the resistance of the galvanometer. As $R >> G$, G can be neglected in comparison to R.

$$\therefore c = \frac{V}{R} \quad \dots \quad \dots \quad \text{(iv)}$$

$$\text{or } c = \frac{R_1 E}{R(R_1 + R_2)} \quad \dots \quad \text{(v)}$$

From the theory of the ballistic galvanometer, we know that,

$$Q = K\theta(1 + \lambda/2) \quad \dots \quad \text{(vi)}$$

Where Q is the charge passing through it, θ the first kick, λ the logarithmic decrement and K the constant of the ballistic galvanometer when steady current is passed through ... meter. K then, is given by the relation,

$$K = \frac{T}{2\pi} \cdot \frac{c}{\phi} \quad \ldots \quad \ldots \quad \text{(vii)}$$

where, T is its periodic time, and ϕ the steady deflection produced in it due to the flow of current c through it.

Knowing all the quantities mentioned in eqn. (vii) K can be calculated.

Method:—This experiment is generally set in a dark room, and the throw of the galvanometer is measured by lamp and scale arrangement.

Setting of the galvanometer:—

1. Usually, you would find the galvanometer in more or less a set position. Assuming that, it is correctly set, following procedure is recommended.—

Study the given galvanometer very carefully and find out what type of clamping arrangement is provided in it

2 Release its coil with the help of the clamping arrangement.

3. With the help of a spirit level, level it properly, usually it stands on three adjustable legs

4. Opposite the galvanometer, at a distance of one meter or so, keep your lamp and scale arrangement.

5. See carefully whether the lamp is to be lighted by a 6 volt line or a 220 volt line. Accordingly light it.

6. Adjust the height of the lamp and the scale, so that a spot of light after getting reflected from the galvanometer falls on the scale.

7. Focus it by adjusting the lens fitted in the lamp. It is more convenient to first catch the spot of light on an opaque screen near the galvanometer, and then move it till we reach the scale. This setting always needs some practice. As far as possible the spot should lie at the zero of the scale.

8. Now look carefully towards the galvanometer coil. See that it hangs symmetrically round the soft iron core without touching its pole pieces.

9 Slightly blow in to the galvanometer or gently touch its terminals so that its coil is slightly deflected and begins to oscillate. Now see that the coil oscillates *freely* and spot of light returns to its zero and initial position. Thus the galvanometer is ready and set for the experiment.

Making connections:—

10. Make neat and tight connections as shown in fig. 2. Put a tapping key in parallel to the galvanometer coil. It is called the damping key, and is used only when we want to stop the oscillations of the coil.

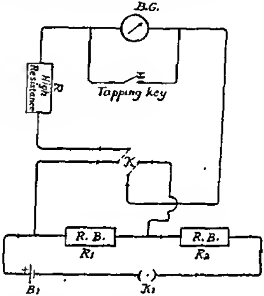


Fig. 2.

11. Connect the accumulator B_1 in series with two resistance boxes and a key K_1. *Introduce a small resistance* R_1 (of the order of 1 to 10 ohm.) in one of the resistance boxes and a *high resistance* R_2 *(of the order of 100 to 500 ohm.)* in another.

12. Connect the two opposite terminals of the commutator key K to the two terminals of the resistance box containing small resistance R_1 connect the other two opposite terminals of K to the two terminals of the ballistic galvanometer through a high resistance R (a 10,000 ohm. resistance coil should be taken).

To determine ϕ :—

13. *Close the key K_1 and the cummutator K, so that a* steady current flows through the galvanometer, and its coil gets deflected. *Consequently, the spot of light will also get deflected*

Adjust the two resistances R_1 and R_2 in such a way that a *convenient deflection of the spot is obtained on the scale.* See that the spot in no case moves *out of the scale.* (current in the galvanometer should not exceed a few micro-amperes. If E=2 volts, R=10,000 ohm. R_1=1 ohm., and R_2=100 ohm., C will be = 1·9 micro-amperes). Determine the steady deflection of the spot on the scale. Let it be ϕ_1.

14. Reverse the current in the galvanometer with the help of the commutator as shown in fig 3. Now the spot will be deflected on the other side of the scale. Note down this deflection. Let it be ϕ_2.

15. Determine mean of ϕ_1 and ϕ_2. It gives ϕ. It completes one set.

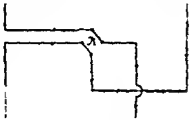


Fig. 3

16. Now change the values of R_1 and R_2 and repeat the above procedure, and determine the deflection ϕ in each case. In this way take 4 to 5 different sets of observations.

To determine the periodic time T —

17. Pass a small momentary current through the galvanometer and then switch off the current. It gives a kick to its coil, and the latter begins to oscillate freely. Determine time for 10, 15 and 20 oscillations with the help of a stop watch, and find out the mean time T for one oscillation.

18. Calculate the current c by equation (v) and thence determine the value of c/ϕ for each set. Find out the mean value of c/ϕ.

19. Knowing T and c/ϕ, calculate K by equation (vi).

Observations.—

(1) Distance of the scale from the galvanometer =... cm.

(2) E. M. F. of the accumulator (E) =... volts.

(3) The value of the high resistance (R) =... ohm.

(4) *Table for determining ϕ:—*

S. N.	R_1 in ohm.	R_2 in ohm.	Current in one direction			Current in reversed direction			Mean deflection $\phi = \frac{\phi_1 + \phi_2}{2}$ in mm.
			Position of the spot		Deflection ϕ_1 in mm.	Position of the spot		Deflection ϕ_2 in mm.	
			Initial	Deflected		Initial	Deflected		
1									
2									
...									
...									
5									

5. Table for determining periodic time T :—

S. N.	No. of oscillations	Time in sec.	Time period T in sec.	Mean T in sec.
1	10			
2	15			
3	20			

Calculations—Calculate c and ϕ for each set, and then determine the mean value of c/ϕ. Knowing c/ϕ and T, calculate K by formula (vi).

Calculation table :—

S. N.	R_1 in ohm.	R_2 in ohm.	R in ohm.	Deflection ϕ in mm.	$c=\frac{E R_1}{R(R_1+R_2)}$ in amp.	c/ϕ	mean c/ϕ	$K=\frac{T}{2\pi}\cdot\frac{C}{\phi}$
1								
2								
3								
4								
5								

Result:—The constant of the given ballistic galvanometer = ... coulombs per mm.

Precautions and sources of error:—1. See that the galvanometer is *properly levelled*, and the coil is free to move, without touching the pole pieces.

2. A damping key should always be provided to check the undue swinging of the coil.

3. An accumulator of *steady e. m. f.* should be used.

4. A very small current should be passed through the galvanometer, otherwise it will be damaged.

5. Do not unnecessarily touch the galvanometer, otherwise its setting will be disturbed.

6. After doing the experiment, do not forget to clamp the coil

Modification.—To determine the value of the logarithmic decrement.

Hints—See experiment No 37.

Oral questions—1. What is a ballistic galvanometer? 2. How does it differ from an ordinary moving coil galvanometer? 3. Why its periodic time is made large, and electro-damping small? 4. What is electro-damping and how is it reduced in this case? 5. Why the coil is of large moment of inertia? 6. What do you understand by constant of a ballistic galvanometer? 7. What are the factors upon which depend this constant? 8. Will it be affected if the distance of the scale from the galvanometer is altered? 9. Why is it called steady deflection method? 10. What is current *sensitivity*? 11. Why only small current should be passed through these instruments? *How it is secured in practice?* 12. Why a damping key is used? 13. Why a high resistance is connected in series with the galvanometer coil? 14. *Do you know* any other method of determining this constant? 15. Why these galvanometers give only a throw when momentary currents pass through them? 16. What is logarithmic decrement, and how is it determined? 17. How can you determine the angle of dip by this instrument?

EXPERIMENT No. 39

Experiment:—To determine the constant of a moving coil ballistic galvanometer by using a standard condenser.

Apparatus:—A moving coil ballistic galvanometer, lamp and scale arrangement, a known capacity, an accumulator, a voltmeter, a Morse Key, a stop-watch, tapping key, connecting wires etc.

Theory:—We know that, if Q amount of charge flowing through a ballistic galvanometer produces a sudden deflection of θ_1, then,

$$Q = \frac{C\,T}{2\pi\ nAH}\theta_1 = K'\frac{T}{2\pi}\,\theta_1 \quad \ldots \text{(i)}$$

$$= K\theta_1 \quad \ldots \quad \ldots \quad \ldots \text{(ii)}$$

Where C is the couple per unit twist, A the area of the coil, n the number of turns in the coil, H the megnetic Field, T the period time, and K the constant of the ballistic galvanometer or ballistic reduction factor.

If this deflection is corrected for damping, we get,

$$Q = K\theta_1\,(1+\lambda/_2) \quad \ldots \quad \ldots \quad \text{(iii)}$$

Where λ is called the logarithmic decrement, and is given by,

$$\lambda = \frac{1}{n-1} \times 2.3026 \log_{10}\frac{\theta_1}{\theta_n} \quad \ldots \quad (iv)$$

Where θ_1 and θn respectively stand for lst and nth deflection throw on the either sides.

Let a condenser of capacity C be first charged to a potential V, and then discharged through the galvanometer. Let this charge Q produce a throw θ_1 in the galvanometer, then we have,

$$Q = CV = K\theta_1\,(1+\lambda/_2) \quad \ldots \quad \text{(v)}$$

Knowing C, V, λ, and θ_1, K can be calculated.

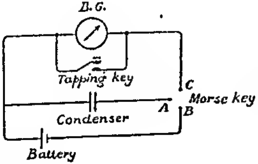


fig. 1.

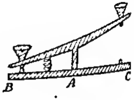


Fig. 2

Method:—Make neat and tight connections as shown in. Fig. 1

Settlog of the galvanometer:—1. See previous expt. No. 38.

Making connections:—2. Put a tapping key in parallel to the galvanometer coil. It is called the damping key (explained in previous expt.).

3 Connect one plate of the condenser to one terminal of the galvanometer, while the other to the terminal A of a morse key. The other terminal of the galvanometer is connected to the terminal C of the Morse key. Connect one terminal of the accumulator to one plate of the condenser, and the other to the terminal B of the Morse key.

The connections through the Morse key or discharge key are so made that a contact between A and C discharges the condenser through the galvanometer. A sudden contact between A and B charges it by putting it in parallel to the accumulator and simultaneously disconnects it from the galvanometer. *These connections should be very carefully followed.*

4. Choose a suitable capacity. By suitable we mean one which will give a *throw with in the scale.*

5. Press the knob to establish contact between A and B. This charges the condenser to the value of the potential equal to the *e. m. f.* of the accumulator (V). This is usually=2 volts. Measure it accurately with a high resistance voltmeter.

6. Now *release* the knob. *It* disconnects A from B, and establishes its contact with the galvanometer. The condenser discharges sending its charge Q=CV through the ballistic galvanometer.

7. As the throw is sudden, it should be observed carefully.

8. It is better not to note the deflection at the very first time. Having known it approximately, focuss the eyes on the approximate position of the spot. previous to the discharge, and then note the throw when the charge is passed. It will be the first throw, let it be θ_1.

9. Then, note the eleventh successive throw. If the first throw is on the right, 2nd will be on left, 3rd on right, 4th on left......and 11th on right.

10. If damping is *too much*, you might note fifth or seventh throw as may be convenient.

11. Repeat the above procedure, using different quantities of capacities, and determine the corresponding throws.

12 Knowing C, V, θ_1 and θ_{11} calculate the value of K.

Observations:—

(1) E. M. F. of the accumulator used (V) = ... volts.

(2) Distance of the scale from the galvanometer =...cm.

(3) *Table for θ_1 and logarithmic decrement λ.*

S. N.	Capacity of condenser C in farads	Deflection of the galvanometer coil for the first through in mm.	Deflection of the galvanometer coil for the eleventh throw in mm.	Logarithmic decrement λ $= 2.3026 \frac{1}{10} \log_{10} \frac{\theta_1}{\theta_{11}}$	$K = \frac{CV}{\theta_1(1+\lambda/2)}$
1					
2					
3					
4					
5					
6					

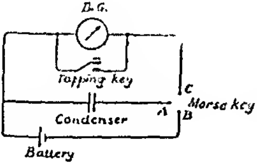
Calculations—It is to be noted that according to theory θ is the angular deflection. But here we keep the distance of the scale fixed, and measure θ as the linear deflection on the scale. Actually this deflection divided by the scale distance is twice the actual angular deflection of the galvanometer coil.

Calculate λ by the formula,

$$\lambda = \frac{1}{10} \times 2.3026 \log_{10} \frac{\theta_1}{\theta_{11}}$$

$$= \dots \dots \dots$$

Knowing C, V, λ, and θ_1, K can be calculated.



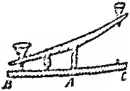


Fig. 2

fig. 1.

Method:—Make neat and tight connections as shown in Fig. 1

Setting of the galvanometer:—1. *See previous expt.* No. 38.

Making connections:—2. *Put a tapping key in parallel to the galvanometer coil. It is called the damping key (explained in previous expt.).*

3 Connect one plate of the condenser to one terminal of the galvanometer, while the other to the terminal A of a morse key. The other terminal of the galvanometer is connected to the *terminal C of the Morse key. Connect one terminal of the accu*mulator to one plate of the condenser, and the other to the terminal B of the Morse key.

The connections through the Morse key [illegible] discharge key are so made that a contact between A [illegible] con-denser through the galvanom[illegible] A and B charges it by [illegible] and simultaneously d[illegible] *connections should be* [illegible]

4. Choose a [illegible] which will give a [illegible]

5. Press th[illegible] B. This charges [illegible] equal to the e. m. f. [illegible] volts. Measure it [illegible]

6. Now [illegible] [illegible] its contact

EXPERIMENT No. 40

Experiment:—To determine the angle of dip by means of an earth inductor.

Apparatus:—An earth inductor with large number of coils, moving coil ballistic galvanometer, lamp and scale arrangement, compass needle, tapping key, rheostat etc.

Description:—(a) Ballistic galvanometer :—See expt. no. 39

(b) Earth inductor:—It is a coil of large area and large number of turns, so mounted that it can suddenly rotate through 180°, either along a horizontal or a vertical axis. This rotation is generally secured by a spring arrangement.

Theory—The coil is so placed, that its axis of rotation is vertical, and its plane is at right angles to the magnetic meridian, and then turned through 180°. It cuts the magnetic flux produced by the horizontal component of the earth's field H. Consequently, induced charge Q_1 is generated in the coil and produces a throw θ_1 in the galvanometer, so that,

$$Q_1 = \frac{2n\,AH}{R} = K\theta_1 \quad \ldots \quad \ldots \quad \text{(i)}$$

where n is the number of turns in the coil, A is its area, and R is its radius. K is the constant of the ballistic galvanometer.

If the same coil is rotated through 180° along a horizontal axis, parallel to the magnetic meridian, it cuts now the magentic flux produced by the vertical component of the earth's magnetic field. If Q_2 is the charge produced and θ_2 is the throw in the galvanometer, we have,

$$Q_2 = \frac{2n\,AV}{R} = K\theta_2 \quad \ldots \quad \ldots \quad \text{(ii)}$$

dividing eqn. (ii) by eqn. (i) we get,

$$\frac{V}{H} = \frac{\theta_2}{\theta_1} \text{ or } \tan\phi = \frac{\theta_2}{\theta_1} \quad \ldots \quad \ldots \quad \text{(iii)}$$

where ϕ is the angle of dip.

$$K = \frac{CV}{\ldots} \text{ where } C \text{ is measured in farads, } V \ldots$$

Result—The constant of the ballistic galvanometer (K) = ... when scale is kept ... distance from the galvanometer.

Precautions—1. See previous expt.

2. The observations for logarithmic decrement should be taken when the galvanometer is in the closed circuit.

3. The accumulator used should have a constant e. m. f.

4. The condenser should not be kept connected to the battery for a very long time. At the same time it should be kept for such a time, that is charged fully to the same potential as that of the battery

5. The capacity of the condenser should be known very accurately.

Oral questions—1. See previous experiment. 2. What do you understand by the capacity of a condenser? 3. What are the factors upon which it depends? 4. Why a Morse key is employed to charge and discharge the condenser? 5. Can you use any other key? How can you reduce the throw if it is going out of the scale? 7. Why should the condenser be charged only for a short time? 8. Give the construction of a condenser box.

9. Again give it a sudden rotation through 180° by eleasing the spring. (The resistance in the rheostat should not e charged in this case). Again charge is produced and the oil in deflected. Note this sudden deflection on the scale. t gives θ_2. It completes one set.

10. Now change the resistance in the rheostat, and repeat he above prodcedure to get more sets for θ_1 and θ_2.

11. Calculate the angle of dip by formula (iii) for each et and then determine the mean value of ϕ.

NOTE—In this experiment it is not necessary to determine the distance of the scale form the galvanometer, as it would cancel in calculations, and so θ is measured only in terms of distance on the linear scale. Similarly it is not necessary to find out the logarithmic decrement, which would also cancel.

Observations:—

S.	Deflection on the scale when the axis of rotation is vertical θ_1 in mm.	Deflection on the scale when the axis of rotation is horizontal θ_2 in mm.	$\tan\phi = \frac{\theta_2}{\theta_1}$	$\phi = \tan^{-1}\frac{\theta_2}{\theta_1}$
1				
2				
3				

∴ Mean ϕ = °.

Calculations:— $\tan\phi = \frac{\theta_2}{\theta_1}$

le of dip at ... = ... °.

no. 33 and 39.

upon the setting

ed, is weak it is better to

area, and large number

Oral questions. [illegible] 8. What is the e. m. f. a maximum and [illegible] 9. What is the e. m. f. [illegible] produced depend? [illegible] should be forced through [illegible] 11. Why is it necessary to determine the [illegible] in the [illegible]?

EXPERIMENT No. 41

Experiment:—To determine wavelength of sodium light by Newton's rings.

Apparatus:—Sodium lamp with necessary choke, short focus convex lens, apparatus for Newton's rings with a plano-convex lens of atleast 100 cm. focal length, travelling microscope preferably with vernier constant of 0.001 cm., reading lens.

Description of the apparatus:—It consists of a wooden box having three sides and bottom closed. A transparent glass plate is so fixed diagonally in the box such that it makes an angle of 45° with the bottom. There is a plain photographic plate (all gelatin is to be rubbed off) at the bottom of the box. On the plate, the given plano - convex lens is placed.

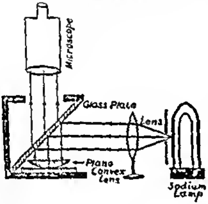


Fig. 1

The travelling microscope should be with a projecting arm so that the wooden box can be placed vertically below the microscope tube. The arrangment is shown in Fig. 1

Theory:—When a lens is placed on a glass plate, a thin air film is formed in between the two. The film is such that its thickness is zero at the point of contact and goes on increasing towards the periphery of the lens. The thickness of the film along a circle with the point of contact as centre is the same and goes on increasing or decreasing as we move outwards or inwards.

When a monochromatic beam of light is incident normally on such a lens, reflection occurs-*one from the lower surface of the lens*, and the other from the *upper surface of the glass plate. Thus, a path difference* is introduced between the two reflected rays 1 and 2 (Fig. 2.) Consequently, intereference takes place giving rise to concentric bright and dark circular fringes known as Newton's rings. As the thickness of the air film is symmetrical along a circle with the point of contact B as centre, the rings so formed are circular.

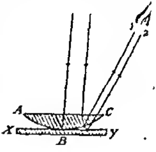


Fig. 2

Let R be the radius of the lower surface of the lens ABC, *which is in contact with the* plane glass plate XY at B. Let t be the thickness of the air film enclosed between the two at any points P and P' equidistant from the point of contact B. Interference will take place between the reflected beams-*one from the point Q lying* on the lower surface of the lens, and the other from the point P, situated on the upper surface of the plate XY They will give rise to a ring. Let its diameter be D i, *e*, Q Q'$=D$.. . Evidently the path difference between these two beams$=2t$.

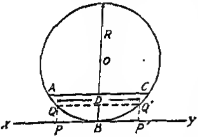


Fig 3

Hence, the points P and P' will lie on a bright or a dark ring according as the path difference,

$$2t = (2n+1)\ \lambda/2 \quad \ldots \quad \ldots\text{(i)}$$

or $$2t = n\lambda \quad \ldots \quad \ldots\text{(ii)}$$; where n is any intiger, and λ is the wave length of the monochromatic light used.

From the geometry of fig. 3, we have,

$$t(2R-t)=\left(\frac{D}{2}\right)^2 \ldots\ldots\ldots\text{(iii)}$$

As t^2 is negligible as compared to R.

$$\therefore 2t = D^2/4R$$

Therefore, if these points P and P' lie on the nth bright ring,

$$2t = \frac{D^2n}{4R} = (2n+1)\,\lambda/2 \quad \ldots \quad \ldots \quad \text{(iv)}$$

Where Dn is the diameter of the nth bright ring.
If P and P' lie on $(n+p)$th bright ring.

$$2t = \frac{D^2(n+p)}{4R} = [2(n+p)+1] \times \lambda/2 \ldots \quad \ldots \text{(v)}$$

Where $D(n+p)$ is the diameter of the $(n+p)$th bright ring.
From equations (iv) and (v) we get,

$$\lambda = \frac{D^2(n+p) - D^2n}{4Rp} \ldots \quad \ldots \quad \text{(vi)}$$

The order of the fringes goes on increasing or decreasing as we move outwards or inwards. Dn and $Dn+p$ are measured with the travelling microscope and R with *spherometer* or by using any optical method.

Method:—Adjustment of box :—1 (a) See that the glass plate at the bottom and the inclined glass plate are *clean and dust free.*

(b) On the glass plate keep the given convex lens in such a way, that its convex surface touches the plate.

(c) Now put the box in such a way that its open side faces the source of light.

2. Adjustment of focussing lens:—In between the sodium lamp and the box keep the lens in such a way that approximately a parallel beam is incident on the inclined glass plate. After reflection at this inclined plate the beam should be incident vertically on the lens surface, as shown in fig. 4.

3. Adjustment of travelling microscope.—(a) Ordinarly one will find that when the above adjustments are made Newton's rings would be visible at the centre of the lens even to the naked *eye* A microscope is to be focussed on it.

(b) When the rings are not visible to the naked eye, microscope becomes difficult and hence the following procedure should be adopted :—

(c) Keep the microscope in such a way that the scale is horizontal and the tube is perfectly vertical.

(d) In the position of the lens, keep a printed paper and *focus the microscope on it.*

(e) Remove the *paper and put lens on the glass plate* so that the centre of the lens lies vertically below the objective of the microscope.

(f) You will definitely see the *fringes* or parts thereof. Slightly move the lens *to bring the centre of the fringes come in view.*

(g) Move the *eye* piece of the tube in such a way that *one wire of the cross wire is parallel to the horizontal scale* of the microscope while the other wire is prefectly at right angles to it.

(h) If you find that the *fringes* are not well illuminated slight adjustment of the *focusing lens would do the job.*

Measurement of diameter of the fringes —

4. (a) Make sure that the fringes formed are well within view.

(b) Clamp the microscope with the clamping screw so that *slow motion screw* can be used *See that by the help of this* slow motion screw the cross wire can be moved from one end of the rings to the other end.

(c) As there is *back-lash in the travelling microscope, go on moving the cross wire, say to the extreme left.* Now move the cross-wire in opposite side and set the vertical wire - say, tangential to one of the bright rings.

(d) It is more convenient to fix the wire in such a way that it lies in the middle of the bright fringe.

(e) From the centre, count the number of this bright fringe. *Say it is 12th.*

(f) Take the reading of the microscope on the *horizontal* scale.

(g) Now move the slow motion screw in the same direction so that the wire moves inwards and fix it on the next inner ring i. e. 11th exactly *in the same position* as above and take the reading.

(h) Repeat the above procedure till you reach to very near the centre-say, upto 3rd or 4th ring.

(i) If you find that these rings are very broad and ıstment of wire exactly in the centre of them is difficult, ıs *over to the right side of the* rings-always moving the slow ıion screw in the same direction.

(j) If you had taken reading up to say 3rd ring on the left, n fix the wire on the 3rd ring on the right side of the centre . take the reading.

(k) Repeat this, till you reach 12th ring on the right ıd side.

(l) Record these observations in a tabular form You l see that for the same ring say 12 th - there are two dings of the microscope - *one on left side of the centre and* ' *other when it is on the right side. Obviously, therefore the* *ference between these two will give the diameter of the 12th* *g.*

(m) Knowing diameters, their squares can be calculated. ıen you can find the difference in squares of 12th and 8th, 11th d 7th, 10th and 6th, 9th and 5th ring. This will thus give a ference between the squares of diameters of rings when $p=4$.

(n) Take mean of these differences of squares and calculate with the help of equation (vi)

5. Measurement of radius of that surface of the convex ns which is in contact with the plate:—

y spherometer :—

(a) Usually the lens is of very big size. As such choose a herometer with as large a leg difference as is available in the boratory.

(b) As it is an extremely important determination in hich the value of h (height through which the central leg l spherometer is required to be raised) is very small, repeat ery observation of the spherometer atleast ten times and then ıth mean observations make calculations of R.

Optical method.—Wherever facilities are available for his method, it should be preferred over the mechanical ıethod.

Observations:—

1. *The given convex lens is plano-convex/biconcave.*
2. The verneir constant of the microscope = ... cm.
3. *Table for determining diameter, when the readings are taken from left to right side:—*

S. N.	No. of rings	Microscope reading when on L.H.S. of the ring in cm. (L)	Microscope reading when on R.H.S. of the ring in cm. (R)	Diameter of the ring (L−R) or R−L) in cm.	Diameter² (D^2)	$D^2_{(n+p)}-D^2_n$	p
1	12					$D^2_{10}-D^2_2=...$	
2	11					$D^2_{11}-D^2_3=...$	
3						$D^2_{12}-D^2_4=...$	
4							
5							
6							
7							
8							
9							
10							
11	5						
12	4						

$\therefore$ Mean value of $D^2_{(n+p)}-D_n^2 = ...$ cm.

4. *For determining radius:—*

(a) *The distance between the two legs of the* spherometer $(a) = 1.$ ... cm; 2 ... cm; 3. ... cm.

mean (a) ... = ... cm.

(b) Pitch ... = ... cm.

Initial reading on glass plate	Final reading on convex surface	Mean initial reading	Mean final Reading	Height h in cm.

Calculations:—One method of evaluating has already n explained in observation table and method.

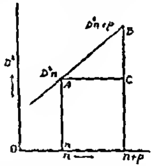


Fig. 4

The other method is to draw a graph between number fringe on X axis and the square of its diameter on the Y axis. u shall get a straight line. Choose A and B points on the rve corresponding (Fig. 4) to n^{th} and $(n+p)^{th}$ ring. Draw tical lines from A and B and a horizontal line from A intersec-g at C. Then BC denotes $D^2_{(n+p)} - D^2_n$ while AC gives p.

$$\text{Radius of convex lens } R = \frac{a^2}{6h} + \frac{h}{2} = \ldots \text{ cm.}$$

Wave length of sodium light will be.

$$= \frac{D^2_{(n+p)} - D^2_n}{4 R p}$$

Result:—Wave length of D lines of sodium = ... cm.

= ... A°

Sources of errors and precautions—1. The glass plate used should be optically plane. Approximately this condition is satisfied by having a photographic plate from which all chemicals have been removed.

Want of this plainness will not give you perfectly circular fringes.

2. It is preferable to use a *plano-convex lens* so that only normal refraction occurs at the first surface. In addition, the convex surface should also have large radius for the same reasons.

3. Another advantage which *we get is that* the thin film extends over large surface so that we get fringes having large diameters. This reduces the percentage error both in the measurement of diameter of rings as well as of radius of the surface.

4. It is necessary that the incident beam is horizontal and parallel so that after reflection at the inclined plate the incidence is *normal* on the lens surface and hence at the air film. As the source of light is not a point but broad source, this *condition is only approximately achieved.*

5. Though it is immaterial whether we use dark or bright fringes for measurement, yet it is found in practice more convenient to use bright fringes. This helps in setting of the cross wire on account of contrast which it provides.

6. It is very necessary that we measure the diameter of the fringes and not its chord. For this, in addition to the process suggested in method it is advisable first to bring the intersecting point of the two wires of the cross wire on the centre of the fringes.

7. Do not measure diameter of the first few rings as *they are too thick and adjustment of cross wire becomes difficult.*

8. *Before start of the work* see that the motion of the slow motion ––––– covers the whole range of the rings to be measured.

9. *Take every precaution to see that the slow motion screw is only moved in one direction only to avoid back lash error.*

10. Remember that the fringes are localised and are formed in between the lens and the glass plate. But when we observe them they are seen through the lens surface and hence are modified. So that this modification is negligible we should use as thin a lens as possible. Then the principal plane of the lens will be very close and we might assume that the fringes are formed in principal plane of object space. This assumption would give unit magnification and the modification in the diameter of the fringes would be negligible.

It is preferable if the glass plate could be placed on the top of the lens to give the thin film. The reflection through thin glass plate would be negligible However, there are practical difficulties in this and hence is not followed.

11. *The centre of the fringes should be dark but sometimes it is bright on account of some dust particles in between. To avoid this the lens should be perfectly cleaned.*

Modification:—To determine refractive index of a given liquid with Newton's rings.

Theory:—When the thin film formed is of air we have

$$\lambda = \frac{D^2_{(n+p)} - D^2_n}{4p\,R} \quad \ldots \quad (1)$$

and when the thin film formed is of given liquid of refractive index μ we have,

$$\lambda = \left[\frac{(D')^2_{(n+p)} - (D'_n)^2}{4p\,R}\right]\mu \quad \ldots \quad (2)$$

Dividing eqn. (2) by (1) and solving we get,

$$\mu = \frac{D^2_{(n+p)} - D_n^2}{(D')^2_{(n+p)} - (D'_n)^2} \quad \ldots \quad \ldots \quad (3)$$

where $D'_{(n+p)}$ and D_n' respectively donote diameters of $(n+p)^{th}$ and n^{th} fringe when the medium is liquid.

Procedure:—The method for the determination of D_{n+p} and D_n in air is the same Having done this, put a few drops of liquid on the glass plate and over it keep the lens so as to form the liquid film instead of air film. Then follow the same procedure as above to determine D'_{n+p} and D'_n. Then calculate λ with the help of the above formula.

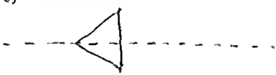
It will be observed that the rings are shortened in a liquid film.

For this experiment, as is obvious, determination of R is not required.

Criticism—The air film in this experiment should be thin, and the incidence of the rays should be normal, otherwise the formula employed will not hold good. The percentage error will be minimised if the diameters of the rings and the radius of curvature of the convex surface are determined accurately. Lesser will be the error in the determination of diameter if it has a large value. Consequently, the convex surface of the lens should possess large radius of curvature.

Oral questions.—1. What do you understand by the phenomenon of interference ? 2. How does it take place in this particular experiment ? 3. Why the Newton's rings formed are circular ? 4 Where are they formed ? Why the central spot is black ? Can it be bright also, if so, when ? 6 Why the rings are broader near the centre, and crowded as we move outwards? 7. What will happen if the air film is not of uniform thickness ? 8. What are the factors upon which depend the diameter of the rings ? 9. Can the plate be placed above the lens? 10 Why a broad source of light is needed in this experiment ? 11 Why the radius of the convex surface should be large ? 12 Can you use a biconvex lens also ? 13. Why the plate should be thoroughly cleaned, before putting lens upon it ? 14. Can you use white light instead of monochromatic yellow light ? What difference would it make in the formation of rings ? 15. Can you determine the refractive index of the liquid by this method ?

(i)



EXPERIMENT No. 42

Experiment:—To determine the wave length of a monochromatic source of light with the help of Fresnel's biprism.

Apparatus:—A stable optical bench, biprism of almost 180°, sodium lamp, a lens with small aperture having smaller focal length.

Description:—Biprism:—It is made up of two prisms of very small refracting angle (of the order of 1° or less than 1°) placed base to base, forming a single obtuse angled prism. In practice, it is ground from the same optically true glass plate.

Optical bench:—It is of a solid cast iron base, carrying a metal scale graduated in millimeters along its length and carries a

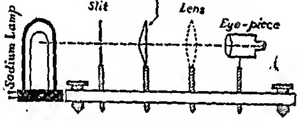


Fig 1

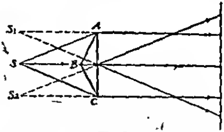


Fig. 2.

vernier. It supports four uprights one each for the slit, bi-prism,

lens and the eye piece. Eye piece can be moved transversely to the bench and its position can be noted on the scale.

Theory—A biprism is simply a device to give two virtual coherent sources of light lying very close to each other. Such two narrow and coherent sources naturally, according to the conditions of interference of light, *give rise to equally spaced dark and bright fringes. They are respectively formed as the path difference between the two beams is an odd number of half wave lengths or an even number of half wave lengths.*

If x = fringe width i. e. the distance between two successive maxima or minima of two fringes,

d = distance between the two coherent sources,

D = distance between source of light i. e. slit and the screen i. e. eyepiece where the fringes are observed and measured,

$$\lambda = x \frac{d}{D}$$

Method—1. Before performing the experiment study the apparatus closely and understand the *functions of various screws etc. provided in the various optical stands.*

Setting the slit vertical :—

2. Level the optical bench with the help of a spirit level and levelling screws. Usually the bench has a three point support and as such it is more stable and can be easily adjusted for levelling.

3 Focus the eye piece on the cross wire against a white background till the cross wire appears to be distinct. Then next rotate the cross wire till one of it becomes vertical This is done visually or with the help of a plumb line when more accurate results are expected.

4 Now bring the eye piece stand close to the slit and adjust their heights to the same level.

5 In order to make the slit vertical rotate it by means of a tangent screw provided in the stand. For verification, it is better to introduce a convex lens in between the slit and eye piece and to project the image of the slit on the eye piece. If the image of the slit is parallel to the cross wire, it is vertical.

Mounting of Biprism :—

6. *Mount the biprism with its edge vertical on the* upright placed next to the slit. It is immaterial as to which face is facing the slit.

7. Adjust its height so that it comes to the same level as the slit and the eye piece.

8. Next rotate the upright in such a way that its base is perpendicular to the length of the table.

9. *Make the slit as narrow as possible.*

10. Keep your eye on the opposite side of the slit. You will see *two virtual images of the slit*. Move the eye at right angle to the bench to and fro. As you move your eye you will find that one of the images *jumps across* the edge of the biprism.

If the edge of the biprism is parallel to the slit the image as a whole will *suddenly cross from one side to the other.* If it is not parallel, either the upper or the lower portion will cross.

So with the help of tangent screw rotate the upright in such a way that the edge of the biprism becomes parallel to the slit as is judged by the sudden transition of the image.

11. If you now look through the eye piece you will see a set of equidistant straight fringes. If necessary make the slit narrower and give *slight rotations* to the biprism by tangent screw to make the system of fringes more distinct.

To make the line joining slit, biprism and eye piece parallel to the length of the table :—

12. By displacing the cross wire with the help of circular scale focus it on one of the fringes.

13. Move the eyepiece away from the biprism. The fringes appear to *expand* but the cross wire must remain on the same fringe.

If the fringes move across the cross wire, this shift is called *lateral shift* and occurs when *all the three, slit, biprism and eye piece are not in one straight line and parallel to the optical bench.*

Therefore, displace the biprism optical stand at right angles to the optical bench till this lateral shift disappears.

Now we are in a position to start the measurements.

Measurement of fringe width —

14 *Fix the eye piece at such a position so th fringes appear to be neither excessively narrow nor exces broad.*

Read the main scale and the circular scale and fi the least count.

15. *Now adjust the cross wire on one of the fr It is better to fix the cross wire in the middle of the fr* Note the reading Then shift it to the next fringe and n the reading. Thus go on taking reading of the succe fringes. Note your observations as shown in the table.

As shown calculate the fringe width correspondin ten fringes by subtracting reading of 1st fringe from elev 2nd from twelth, 3rd from thirteenth etc. *After taking mean, calculate fringe width for one fringe.*

Measurement of D i.e distance between source (slit) screen (eye piece) :—

16. *Note the position of the slit and of the eye pi* stand. This should give D, but we know that D is actu the distance between the slit and the focal plane of the e piece. Therefore to know correct D we have to apply - so say - bench correction - as explained later.

Measurement of $S_1S_2 = d$ = distance between two virtu sources :—

17. *See that the positions of slit and* biprism remai *unchanged.*

18. Keep a spare upright between the biprism and th eye piece and *mount a convex lens on it. It is better to cove* the peripheral portion of this lens and to leave a small circular aperture in the centre to obtain well defined straight images of virtual slits. The lens should be of *shorter focal length* and never greater than 25 cms.

19 Fix the eye piece away from the slit at a distance greater than *four times the focal le*

20. Now move the lens in between the eye piece and : biprism till we get *well defined, well focussed images* of the o virtual slits in the field of view of the eye piece. At this ne suppose the lens is more near to the eye piece.

Then move the lens more near the slit and again t the well focussed images in the eye piece. You will find at they are much enlarged. Sometimes you may find that the iages are so enlarged that you cannot see both of them nultaneously in the field of view. *For the sake of convenience is always better to have both of them simultaneously in view.*

When you find that the distance between slit and eye ece is proper to get the above position, put the lens in the vo positions mentioned above and each time measure the stance between the two images as seen in the eyepiece. Let ı call these respectively d_1 and d_2.

The distance d between two virtual images of the slit is ven by $d = \sqrt{d_1 d_2}$

etermination of Bench correction for D :—

21. Remove the biprism. Take a T rod of known ngth. Let it be x cm. Now hold the rod parallel to the ench in such a way that its one end just touches the slit. ocus the eye piece on the other end. Read the positions of the it and the eye piece on the bench. The difference gives y the pparent length of the T rod.

Hence the bench correction = Actual length of T rod –Apparent length of T rod as measured $= (x-y)$ cms.

Now this bench correction is to be algebrically added to he value of D-measured as explained in step No. 16. That vould give the final corrected value of D.

22. The above completes one set. For second set, the istance between slit and biprism may be changed and again neasurements for x, d and D may be made.

Observations :—Smallest division (or Pitch) on main scale = cm.

No. of divisions on the circular scale = cm.

Least count ... ... = cm.

1. Table for measurement of fringe width x :—

No. of fringe	Micrometer reading of the eye piece (A)	No. of fringe	Micrometer reading of the eye piece (B)	Fringe width for 10 fringes (B−A)
1		11		
2		12		
3		13		
4		14		
5		15		
6		16		
7		17		
8		18		
9		19		
10		20		

Mean Fringe width for 10 fringes = ...cm.
Fringe width for one fringe x = ...cm.

2. Measurement of S_1S_2 = d = distance between two virtual sources :—

The approximate focal length of the lens used = ...cm.

The distance between slit and eye piece = ... cm.

S. No.	Micrometer readings when lens is more near the slit		d_1 $=P-Q$	Micrometer readings when lens is near the eye piece		d_2 $=P'-Q'$	$d=\sqrt{d_1d_2}$
	1st image P	2nd image Q		1st image P'	2nd image Q'		

3. Measurement of D = distance between slit and eyepiece where the measurement of fringes was undertaken :—

Actual length of T rod $= x$ ... cm.
Apparent length of T rod as measured
on the optical bench, $= y$ ... cm.
$\therefore$ Bench correction $= x - y$ ... cm.

Hence the corrected D = observed D + Bench correction.

Position of slit	Position of eye piece where fringe width was measured	Observed value of D	Corrected D

Calculations :—

$$\lambda = x \frac{d}{D}$$

Substitute the values from above and calculate λ

Result :—The wave length of sodium light = ... cm.
= .... A°

Precautions :—1. The slit, biprism edge and cross wire must be vertical and be in a line parallel to the optical bench.

2. The slit should be *as narrow as possible.*

3. The *back lash error of the micrometer screw should be avoided by moving it only in one direction while taking measurements.*

4. The eyepiece stand should be so fixed that the movement of the eyepiece is at right angles to the optical bench.

5. The *diffraction fringes are sometimes formed. These are not equidistant fringes and so should not be confused with the equidistant interference fringes.*

6. The distance between slit and eye piece should be properly set to get two positions of the lens for measuring d_1 and d_2.

7. The axis of the lens must be parallel to the optical bench.

8. For finding fringe width or d, the position of the cross wire always must be fixed in the same way.

9. While measuring D, bench correction should always be taken into account.

Criticism :—The *chief source of error* in this experiment, is introduced due to the want of parallelism between the slit, the bi-prism edge and the cross wire. The line joining the former two should also be parallel to the base of the bench. If it is not so, the fringe width will not remain x, but it will become $x\ \phi$ where ϕ is the angle between the line joining the slit and the edge of the bi-prism and the length of the bench. Hence the accuracy of the result will be impaired, and that is why this adjustment should be done very carefully.

Oral Questions :—1. *See* expt. No. 41. 2. Why two coherent sources are required to produce interference of light? 3. Will interference take place between the light given by two different candles? Why mono-chromatic light should be employed in such experiments? 5. Give the construction of a Fresnel's bi-prism. 6. How two coherent sources are obtained in this case? 7. What are the main adjustments and how are they done? 8. What harm will be done if the slit, bi-prism edge and the cross wire are not parallel to each other? 9. What do you mean by the lateral shift of the fringes? How is this shift removed? 10 What are the main precautions taken while doing this experiment? 11. What are the factors upon which depends the width of the fringe. 12. Why a lens of short focal length is used for measuring d? 13. How will the width of the fringe change, as the eye piece is removed away from the biprism?

EXPERIMENT No. 43

Experiment :—To determine the wavelength of sodium/mercury light with the help of plane diffraction grating.

Apparatus :—Source of light - sodium/mercury lamp, spectrometer with reading lens, plane diffraction grating of known grating element.

Description of apparatus :—Spectrometer :—See expt. No. 14.

Grating :—On a plane surface are drawn a very large number of straight lines so that we get a number of slits of width *a*, seperated by an opaque distance of *b*. $(a+b)$ is then called the *grating element* and gives the distance between centres of two corresponding slits.

The number of lines drawn are usually from 12,000 to 30,000 per inch and the length of ruled surface is from 2" to 5".

For usual work the grating used is replica type and hence, it *should not be touched for fear, that the gelatine might be rubbed off.*

Theory :—When a parallel beam is incident on a slit, the diffraction pattern which we get has a central maximum with other orders of maxima of falling intensities on either side. When we have a number of parallel slits like these as in plane transmission grating, in addition, we get interference between these large number of beams. As a result, we get sharp and bright line spectrum separated

Fig. 1

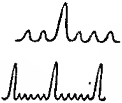


Fig. 2.

by wide dark regions. This dark region corresponds to the large number of secondary maxima of very low intensities. *Thus, it is possible to get not only the direct image of the beam, but a number of secondary deviated images at different angles.*

The angular seperation between the zero order and *n*th order of primary spectrum (Maxima) is given by

$$\text{Sin}\ \theta = \frac{n}{a+b}\ \lambda \ldots\ldots\ldots\ldots\text{(i)}$$

where, θ is the angle of diffraction or angular separation between zero and the nth order.

λ is the wave length of the colour of light used, end $(a+b)$ is the grating element.

$$\text{or}\ \lambda = \frac{(a+b)\ \text{Sin}\ \theta}{n} \quad \ldots \text{(ii)}$$

Method :—1. Adjustments of spectrometer to make the incident beam parallel, and to set the telescope for parellel rays etc. See expt. No. 14.

2. Setting of the grating so that incidence is normal on it :—

(a) Rotate the telescope and bring it in line with the collimator so that *the image of the slit is formed on the intersection of the cross wire of the telescope.* If necessary, clamp the telescope and give it slow motion for finer adjustment.

Remember that while this adjustment is being made, the prism table is *already clamped.*

(b) Take the reading on the scale. Read both the verniers. Call these readings *a* and *a'* respectively.

(c) Fix the given grating on the turn table. If you have the choice adjust it in such a way that the ruled surface of the grating is at the centre of the table and *is at right angles to the lines drawn on it.*

(d) Generally to save the ruled surface from damage, en extra glass plate is put on the grating. If so, see that the

see that the extra glass plate faces the *incident beam.*

(e) Now turn the telescope from its initial position through exactly 90°, so that the new readings are $a+90$ and $a'+90$. Clamp the telescope. This now ensures that the collimator and the telescope tubes are at right angles to each other. See fig. 3,

(f) Now rotate the turn table carrying the grating in such a way that the image of the slit after reflection at its surface falls on the intersection of the cross wires of the telescope. If the slit image is not in the centre of the field of view, the two adjusting screws of the turn table at right angles to the length of the grating, might be slightly adjusted.

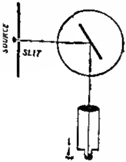


Fig. 3

(g) To verify that your adjustment is correct you might further rotate the telescope by 180° and again turn the turn table, to get the reflected image, at the inter-section of the cross wires.

(i) Now under these conditions, *the grating is so placed that the incidence is at 45°.*

So turn the turn table through 45° or 135° so that its surface is *at right angles to the incident beam and the ruled surface faces the beam.*

Setting of the grating so that its ruling becomes parallel to the axis of rotation of the instrument :—

3. (a) It is assumed that when seen directly, the image of the slit is formed on the inter-section of the cross wire exactly symmetrically.

(b) Now turn the telescope to catch the 1st order spectrum and see, that again the image comes symmetrically on the inter-section of the cross wire. If it is not so, adjust one of the levelling screws at right angles to the grating, to achieve this,

To make the slit parallel to the rulings of the grating :—

4. When the telescope is set on the first order spectrum very carefully rotate the slit of the collimator, and see that the spectrum becomes more well defined and bright. This is such setting, that approximately it can be done visually, and hence only slight rotation of the slit might be needed.

It is also to be remembered that the collimator is already focussed for parallel rays, and hence while rotating the slit its distance from the collimator lens should not be changed.

5 Measurement of the angle of diffraction :—

(a) Now substitute the source of light, the wave length of which is to be determined.

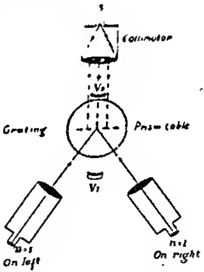


Fig 4.

(b) See that except for ... screws are properly clamped.

(c) Adjust the telescope ... Clamp it, and by slow motion ... the cross wire exactly in the ...

(d) Note the readings on both the verniers-V_1 and V_2. Normally the difference in their readings would be approximately 180°.

(e) Now bring the telescope on the first order spectrum of the same line, on the other side of the normal, and take readings of the two verniers.

(f) *Remember that while recording your observations, you do not make any confusion in noting readings of V_1 and V_2.*

Also note that after crossing 360°, the readings on the scale would start from 1,2 etc.

(g) *The difference between two readings of the same vernier gives double the angle of diffraction.*

(h) Knowing the number of lines drawn to an inch, the grating element is determined and hence λ is calculated.

(i) Repeat the above procedure for studing the spectrum of higher orders.

Observations :—

[1] *Particulars of spectrometer scale :—*

(i) Smallest main scale division = ...degrees..... min.

ii) Total No. of vernier divisions... = ...

iii) Least count = ... sec.

[2] *Setting of grating for normal incidence .—*

		V_1	V_2
(i) Reading on the scale when collimator and telescope are in line i. e. (α) and (α')	=	..	...
(ii) Reading on scale when collimator and telescope are at rt. angles i. e. (α+90) and (α'+90)	=	...	...
(iii) Reading on scale when the grating is turned through 45 or 135°	=	...	

To make the slit parallel to the rulings of the grating :—

4 When the telescope is set on any first order spectrum very carefully rotate the slit of the collimator, and see that the spectrum becomes more well defined and bright. This is such a setting that approximately it can be done visually, and hence only slight rotation of the slit might be needed.

It is also to be remembered that the collimator is already focussed for parallel rays, and hence while rotating the slit its distance from the collimator lens should not be changed.

5 *Measurement of the angle of diffraction :—*

(a) Now substitute the source of light, the wave length of which is to be determined.

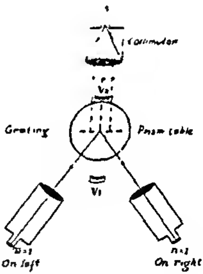


Fig 4.

(b) See that except for telescope, all other screws are properly clamped.

(c) Adjust the telescope on the first order spectrum. Clamp it, and by slow motion screw bring the inter-section of the cross wire exactly in the middle of the spectrum line.

. . [4] *Determination of grating element* $(a+b)$:—

(i) No. of lines drawn on the grating = ... per inch

∴ grating element = ... per inch

and " " = ... per cm.

Calculations :— $\lambda = \frac{(a+b)\ \text{Sin}\ \theta}{n}$

= ... cm.

= ... A.

Calculations should be performed by putting $n = 1$ and 2 etc. with corresponding values of θ.

Result:—The wave length of ... ... = Cm = ... A.

Sources of errors and precautions :- See expt. No 14.

2. *Do not touch the grating surface,* but hold it from its edge.

3. Sometimes, as a precaution a plane glass plate is put on its ruled surface. If it is not there, while adjusting see that the ruled surface faces collimator and not the telescope. If the glass plate is there it is immaterial which face faces the telescope.

4. Clamping of telescope and table must be studied before the start of the experiment. Both the things should never remain unclamped, Remember that one rotates the vernier while the other the main scale. If you want to rotate the telescope see that the table is firmly clamped Also if you want to give slow motion to the telescope, it should be clamped.

5. *Reading of both the verniers is essential.* This eleminates the error, due to the axis of rotation not passing through the centre of the graduated circle.

6. *The adjustment of grating for normal incidence must be done very carefully,* An error in this, causes appreciable deviations in correct result. Therefore, use of grating in minimum deviation position is recommended.

Modification : I—To use plane diffraction grating in the minimum diviation position, and to determine wave length of light.

Theory :—When the incidence is oblique.

$(a+b)\ (\text{Sin}\ i + \text{Sin}\ \theta) = n\ \lambda$, where angle of dence is i.

[3] *Determination of the angle of diffraction* :—

Order of Spectrum	Vernier Scale Reading	Spectrum on the right of the direct image			Spectrum on the left of the direct image			Difference of 2 readings of the same V. S. i. e. (A–B) = 2θ	θ	Mean θ
		M. S. Reading	V. S. Reading	Total Reading (A)	M. S. Reading	V. S. Reading	Total Reading (B)			
1	V_1									
	V_2									
2	V_1									
	V_2									
3										

5. Sometimes, you find that the R.P. of your grating so small that you are not able to distinguish between the two odium lines In such a case, you are asked to take a mercury imp.

6. Recognise all the prominent lines of mercury and nd out their λ (either by experiment or from table, it is better o find it by experiment).

7. Having chosen as large a number of lines as possible, nd out their corresponding angles of diffraction in the same rder.

8. Draw a graph between λ on X axis and θ on Y axis.

9. Find out the slope of the curve at particular points orresponding to certain values of λ. That gives dispersive ower at those values.

Result :—Dispersive power $\frac{d\theta}{d\lambda}$ = ... at λ = ... cm.

Criticism :—The results obtained by the transmission grating are very satisfactory, provided all the precautions are aken in to account. The lines in grating may not sometimes e straight or equally spaced This may introduce some error n the determination of the wave length.

Oral Questions :— What do you understand by the phenomenon of diffraction? 2. What is plane transmission grating? 3. How is it prepared and what is a grating element? 4. Name the various types of diffraction gratings? 5. What is the difference between the spectrums obtained by a prism and a grating? Which is better and why? 6. How you set the grating surface normal to the incident beam. 7. Why this adjustment is so very important? 8. What do you mean by different order of spectras? 9. Define dispersive power and resolving power of a plane transmission grating? What are the factors upon which they depend? 10. Why the minimum position setting of the grating is better than the normal setting? 11. What is the difference between the interference and diffraction? 12. What will be the effect of increasing the number of lines ruled per cm? 13. See experiment No. 14.

Record your table for observations on left of the [illegible]

N.B. Take other observations as explained in main experiment

Calculations —

$$\lambda = 2(a+b)\sin\frac{\theta}{2}$$
$$= \ldots \text{ cm.}$$

Result — Wavelength of light = ... cm. or ... A.

Modification No. 2 — To determine dispersive power of the grating —

Theory — We know that,

$$(a+b)\sin\theta = n\lambda$$
$$\therefore \quad (a+b)\cos\theta\, d\theta = n\, d\lambda.$$
$$\text{or} \quad d\theta/d\lambda = \frac{n}{(a+b)\cos\theta}$$

Here $d\theta/d\lambda$ is called the dispersive power of the grating at wave length λ. Approximately this $d\theta/d\lambda$ can be put as

$$\frac{\theta_1-\theta_2}{\lambda_1-\lambda_2}$$

where θ_1 and θ_2 are the angles of diffraction corresponding to wavelengths λ_1 and λ_2 respectively, in the same order. It is assumed here that λ_1 and λ_2 lie very close to each other.

If a graph is drawn between λ on X axis and θ on Y axis, the slope of the curve at any point would also give the dispersive power.

Method—1. If your grating is such that it is able to resolve the two D lines of sodium, it is best to choose them.

2. *Find out the angle of diffraction in 1st order corresponding to* D_1 and D_2 lines as explained in *main experiment.* Knowing θ_1 and θ_2 and taking $d\lambda = 6\times10^{-8}$ cm., perform calculations. *This gives* dispersive power at $\lambda = 5890\times10^{-8}$cm.

3. Repeat the above procedure for second order.

4. Your result can be verified by the formula

$\dfrac{d\theta}{d\lambda} = n/(a+b)\cos\theta$ *also, where θ is the mean value of θ_1* and θ_2.

2. Place such a sheet opposite a sodium lamp so that *practice we are provided with two fine bright sources of ght. Its plane should be perfectly vertical.*

3. At a distance of a few feet from the plate mount ie given telescope and focus it in such a way that the vo bright line images of the slit are well *within the field of iew.*

4. *See that the axis of the telescope is perfectly hori- ontal and at right angles to the glass sheet.*

5. Now mount the given rectangular adjustable slit ust in front of the objective of the telescope and as near t as possible.

6. Gradually reduce the width of the aperture and ontinue to look through the telescope.

7. A stage will be reached when you will find thet he two line images are just resolved i. e. by closing the perture just a little, the two images disappear end merge into one. Stop at this stage.

8. If it is a directly reading slit, take the reading, or neasure its width with the help of a travelling microscope. This gives d.

9. Measure the distance between the glass sheet and the objective of the telescope. This gives u.

10. Measure the distance between the two slits with the help of a microscope. This gives AB.

11. The above procedure can be repeated for various values of u.

12. For every distance calculate $\frac{AB}{u}$ end $\frac{\lambda}{d}$ and compare the results. This gives limit of resolution of the telescope with aperture d.

EXPERIMENT No. 41

Experiment—To verify the expression for the li[...] resolution of a telescope.

Apparatus—A telescope with a variable rectan[...] aperture of known width, a monochromatic source of [...] two fine objects at known distance i. e. preferably a [...] sheet coated with a tin foil in which two parallel slits a[...] at known distance, a travelling microscope etc.

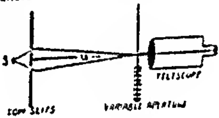


Fig. 1

Theory:— $\theta = \frac{AB}{u} = \frac{\lambda}{d}$ ...(1)

where, θ = limit of resolution of the telescop[...]

AB = the distance between the two fin[...] which serve the purpose of th[...] objects,

u = distance of the objects from the [...]tive of the telescope,

λ = Wavelength of light,

d = width of the rectangular aperture [...] immediately before the objecti[...] the telescope.

Procedure:—If a glass plate with tin foil is not pro[...] you can prepare one. Take a sheet of glass and co[...] with a thick black photographic plate cover. On [...] coating, two slits can be drawn at a distance of 2 to 3 m[...]

Precautions and sources of error :—1. The telescope should be properly focussed because this will affect the expression to a very great extent.

2. Usually expression $\frac{AB}{u}$ gives higher values than $\frac{\lambda}{d}$.

3. The two sources of light A and B should remain perfectly vertical,

4. *Back-lash error* should be avoided while measuring the width of the aperture.

5. To get two readings for the same distance, it is better to measure the width of the slit also by opening the slit for the just resolution of the two objects.

Oral Questions :—1. What is the resolving power of a telescope? 2. What are the factors on which depends the resolving power? 3. How can it be increased? 4. Why the objectives of the telescopes are made up of large apertures? 5. Why the theoretical value of the resolving power generally exceeds the experimental value? 6. Why the width of the variable slit should be measured very accurately?

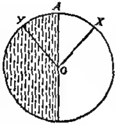
$u = 79 \cdot 5$ $d =$

Observations :—

S.N.	Width of slit for just resolution. d I	Wave length of light II	Limit of resolution $\theta = \frac{\lambda}{d}$ III	Distance of object from telescope u IV	Distance between two objects AB V	Limit of resolution = AB/u VI	The expressions of III and VI colms are nearly equal
1							
2							
3							

Detecting devices :—Half shade plate :— It coosists of two halves — One half is of *quartz* half wave plate cut parallel to the optic axis and of such thickness that it introduces a path difference of $\lambda/2$ between the ordinary and the extra-ordinary beam. The other half consists of a plane glass sheet of such a thickness that absorption of light by both the beams is equal.

For theory in details see a text book of optics.



Eig. 2.

A plane polarised beam passea through the glass plate portion. Let us call its plane as OX. When it passes through the $\frac{\lambda}{2}$ plate it decomposea into ordinary and extra ordinary. On emergence, due to phase difference of 180°, it recombines into plane polarised light but is inclined to the optic axis by an equal amount to the other side. Thus, we get two beams with their plane of polarisation along OX and OY equally inclined to the optic axis OA.

When the analyser is aet in the position shown in diagram, it is aymmetrical with respect to OX and OY and hence both halvea of the field of view appear equally bright On passing through the solution, the plane of polarisation gets rotated. So both OX and OY would get rotated in the same direction. To get aga'n the position of equal illumination, the analyser would be required to be rotated through an equal amount.

Thus, lostead of using only a polariser and an analyser, use of half shade makes the detecting arrangement more sensitive.

By—quartz :—It consista of two semi circular plates of quartz one made of right handed while the other of left handed quartz. These plates are so cut that the optic axis liea at right angles to its faces. The thickness of each plate is chosen to be near about 3.75 mm. so that the yellow light (approx. D lines of sodium) may be rotated through 90°.

When plana polarised white light is incident on this plate, as shown in fig 3 the plane of polarisation of component colours are rotated through different angles.—for red it is least, maximum for violet and 90° for yellow. In two halves the colours are rotated in opposite directions but aymmetrically. If we fix

EXPERIMENT No. 45

Experiment :—To *determine the specific rotation* of *cane sugar solution.*

Apparatus :—Polarimeter *with a sensitive detecting device*, sodium lamp or white lamp depending on the detecting device, beaker, flask, funnel, pipette and a balance etc.

Description of apparatus Polarimeter :—As shown in figure *it consists of three main parts* :—

(a) Collimating tube (b) *tube for solution and (c)* low *power telescope.*

Fig 1

Collimating tube :—At one end a convex lens is so placed, *that it makes the incident beam of light almost* parallel. This beam then, *has to pass through a polariser* (*a nicol*). *The plane polarised* beam so produced is then incident on the detecting device - *which is either a half shade or a biquartz*.

Solution tube :—This is a long cylindrical tube of generally 20 cm. *length.* At both ends *it is closed by means* of optically plane glass plates with the help of metallic caps. In the middle there is the opening for filling the tube with the solution. In some tubes there is an arrangement to *house the* air bubble at the top, if it could not be removed *completely while* filling.

Low power telescope :—*At the end of the tube is* fixed an analyser (a nicol). *The incident beam after passing* through the analyser passes through the eyepiece. With the *eyepiece* is attached a circular scale. Together with it, rotates the analyser.

Remember *that sodium lamp is to be used with half shade and white lamp with biquartz detecting arrangement.*

Molecular rotation:—It is defined as product of specific rotation (α) and molecular weight (M)

$\therefore$ molecular rotation $= \alpha \times M$

Method:—Preparation of Solution :—1. If possible take a flask of capacity 100 c.c. i.e, a flask on which there is a mark showing 100 c.c. level.

2. Weigh it.

3. Put in it some 15 to 20 gm. of sugar and weigh it again, to know the mass of sugar dissolved.

4. Pour a little distilled water in it and prepare a solution

5. Now pour more water so that the level comes up to the mark. Thus we have 100 c.c. solution of sugar of known strength.

6. Generally we find that this solution is not very clean on account of dirt in sugar. So filter it.

Setting of Polarimeter:—7. Find out whether the detecting device is half shade or biquartz.

8. If it is half shade, choose a sodium lamp as source of light. For biquartz we must use white light.

9. Study the circular scale on the eyepiece side, and note the pitch as well as the vernier constant.

10. Rotate the analyser and study the equal illumination or equal tint of passage position carefully. By giving it slow rotation in either direction study if there is any range over which you are not able to distinguish between the adjustment of positions. Generally you will find that this range is negligibly small. However, if no sensitive detecting device were provided you would certainly find a very big range between which you are not able to fix your analyser

11. Fill carefully the polarimeter tube with distilled water in such a way that no air bubble remains inside the tube. Place it in the proper position.

12. Look through the eyepiece. In general you will see that the two halves are of unequal illumination or of different colours.

13. Rotate the analyser till you get the position of equal illumination or same colour position.

14. Note the reading on the scale.

15. Rotate the analyser through 180° and again set its position to obtain equal illumination or same colour position, and take reading. This is initial reading.

Filling with solution and measurement of rotation of plane of polarisation :—

an analyser crossing the red of one half, it won't be cross the red of the other half. But if we keep it crossing yell of one half, it would automatica cross yellow of the other half. As other colours would also be inclin equally in both the halves, t resultant colour produced in ea half would be the same and wou be a mixture of red and viol This resultant colour will be greyi and is called the tint of passage. the analyser is kept in any oth position, as indicated by doub dotted line, there would be prominence of red tint on righ hand side and violet tint on left hand side as is obvious fro the diagram. The tints of two halves therefore would not b the same.

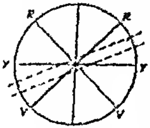


Fig. 3

Hence, the setting of analyser for the position of tin of passage is very sensitive. A slight rotation in eithe direction would make the tints in two halves different.

Theory :—The amount of rotation of plane of polarisa tion of light, when it passes through an optical mediun depends,

(i) directly on the thickness of the optically active medium actually traversed.

(ii) inversely as the square of wave length of light.

(iii) on temperature. It decreases with it.

The specific rotation of a liquid is defined as the ratio of the rotation produced by a decimeter (10 cm) thickness of the substance and its density. In case of solutions, it is defined as the rotation per decimeter length of the solution divided by the number of grams of the substance per c.c. of the solution.

Thus, $\alpha = \dfrac{\theta/l}{x/v} = \dfrac{\theta v}{xl}$

Here, θ = rotation of plane of polarisation in degrees.

v = volume of solution in c.c.

l = length of tube in which solution is filled in decimeters.

x = amount of sugar dissolved in gm.

α = specific rotation.

S. N.	Reading on analyser for tint of passage or equal illumination in degrees													Rotation		
	With distilled water (Initial reading)						With sugar solution (Final reading)									
	First position.			Position after rotating by 180°			Strength of solution in gm. per 100 c.c.	First position			Position after rotating by 180°					
	Main Scale	Vernier Scale	Total (a)	Main Scale	Vernier Scale	Total (b)		Main Scale	Vernier Scale	Total (c)	Main Scale	Vernier Scale	Total (d)	$\theta_1 = (c-a)$	$\theta_2 = (d-b)$	Mean $\theta = \frac{\theta_1+\theta_2}{2}$ in degrees
1																
2																
5 6																

16. Remove distilled water. Put a few c.c of solu in the tube and wash it carefully. Having done this, fill tube completely with the solution and place it again in posi

17. Looking through the analyser, you will find that previous adjustment of equal illumination or tint of passage been disturbed.

18. Rotate the analyser in such a direction as to re the previous position. Take the reading.

19. Again rotate the analyser through 180°, and se position to obtain the same illumination or tint of passage take reading. *This is final reading.*

20. *Determine the difference between the final* *initial readings separately for each position.* This gives angle of rotation of plane of polarisation. Find the mean these two readings.

21. Repeat the above procedure with solution of dif rent strengths. For this, take known volume of solution a mix it with known volume of distilled water. You can no calculate the strength of this new solution *e.g.* suppose you ha dissolved 20 gm. of sugar in 100 c c. solution. Let us take 10 c of this solution. It will have 2 gm. of sugar in it. Make th 10 c c. solution to 15 c.c., by adding 5 c.c. of distilled wate Now we have 2 gm. of sugar in 15 c.c. solution. Therefore,

100 c.c, it would be $\frac{2 \times 100}{15} = 13.33$ gm. *Thus, the strength* *the solution is calculated in gm. of sugar dissolved in 100 c c.* *the solution.*

22. Plot a graph between strength of solution on X axi and rotation of plane of polarisation on Y axis. You will get straight line, from which you can know rotation correspondin to any strength

23. Measure the length of the tube containing suga solution and convert it into decimeter.

Observations :—

(1) a. Mass of the flask ... ... = ... gm.

b. Mass of the flask + mass of sugar = ... gm.

∴ Mass of sugar = b − a = ... gm.

c Volume of solution v = ... c.c.

(2) Length of the tube = ...cm = ... decimeter.

(3) Temperature of the solution = ...°C.

(4) For rotation of plane of polarisation :—

Pitch (or least count) of the m.s. = ...

... number of divisions on the c.s. (or v.s.) = ...

S. N.	Reading on analyser for end of passage or equal illumination in degrees — With distilled water (Initial reading) — First position.			Position after rotating by 180°			With sugar solution (Final reading) — Strength of solution in gm. per 100 c.c.	First position			Position after rotating by 180°			Rotation		
	Main Scale	Vernier Scale	Total (a)	Main Scale	Vernier Scale	Total (b)		Main Scale	Vernier Scale	Total (c)	Main Scale	Vernier Scale	Total (d)	$\theta_1 = (c-a)$	$\theta_2 = (d-b)$	Mean $\theta = \frac{\theta_1+\theta_2}{2}$ in degrees
1																
2																
5 6																

2. Elastic constants

Substance	Young's Modulus (Y) × 10^{11} dynes per sq. cm.	Modulus of rigidity (η) × 10^{11} dynes per sq. cm.	Bulk modulus (K) × 10^{11} dynes per sq. cm.	Pois… rat… (σ…
Alluminium	7·2—7·5	2·5 to 2·7	7·5	·34
Brass	9·7—10·2	3·5	6·0	·34—…
Copper	11·0—12·9	3·4—4·6	13·0 to 14·3	·25—…
Constantan	16·3	6·1	15·5	·32
Iron (wrought)	19—21	7·7—8·3	14·6—16·0	·27
Iron (cast)	10—13	3·5—5·3	9·5—9·7	·23—·3…
Steel (cast)	19—21	7·4—7·6	16·4—17·5	·23
Steel (mild)	22	8—8·9	16—19	·25—·3…
Lead	1·6	·6	4·5	·44
Glass (crown)	6·0—7·8	2·6—3·2	4·0 to 5·0	·20—·2…
Glass (flint)	5—6	2·3	3·7	·22—·26
Phosphor bronze	12·0	4·4	12·1	·329
Silver	7·8	2·2	10·5	·27
Gold	8·0	2·77	16·5	·422
India Rubber	·05	·00015	...	·48

3. *Some important temperatures*

	Absolute scale in degrees	Centigrade scale in degrees
Absolute zero	0	—273
Boiling point of liquid helium	4·2	—268·8
Boiling point of liquid hydrogen	20·3	—252·7
Boiling point of liquid air	83	—190
Melting point of ice	273	0
Estimated temperature of the outer layer of sun	6000	6000 approxi.
Temperature of hottest star	28000	28000 approxi.

4. Properties of solids

Substance	Density gm. per c.c.	Specific heat cal./gm.	Coefficient of linear expansion (a) × 10⁶ per °C	Thermal conductivity cal. cm⁻¹ sec⁻¹ °C⁻¹	Melting point °C under normal pressure
Allumınium	2·70	·22	26	·504	657
Brass	8·4—8·7	·092	18·9	·26	900
Constantan	8·88	·098	16	·054	1300
Copper	8·89	·093	17	·918	1083
Carbon (graphite)	2·22	·16—·2	5—7	·0014	>3500
Cork	·22–·26	·49	...	·00012	...
Glass	2·4—2·8	·16	..	·0025	1000
Gold	19·3	·0316	14	·70	1063
Iron (cast)	7·6	·119	10·2	·114	1100
Iron (wrought)	7·85	·115	11·9	·16	1530
Invar	8·00	·12	9	...	1500
Ice	·916	·5	50·7	·0053	0
Lead	11·34	·0305	27·2	·083	327
Platinum	21·25	·032	9	·165	1773
Quartz (fused)	...	...	·42	—	—
Silver	10·5	·055	19·2	·974	961
Steel	7·7	·11	11	·11	1430

2. Elastic constants

Substance	Young's Modulus (Y) × 10^{11} dynes per sq. cm.	Modulus of rigidity (η) × 10^{11} dynes per sq. cm.	Bulk modulus (k) × 10^{11} dynes per sq. cm.	Poiss... ratio (σ)
Alluminium	7·2—7·5	2·5 to 2·7	7·5	·34
Brass	9·7—10·2	3·5	6·0	·34—·
Copper	11·0—12·9	3·4—4·6	13·0 to 14·3	·25—·
Constantan	16·3	6·1	15·5	·32
Iron (wrought)	19—21	7·7—8·3	14·6—16·0	·27
Iron (cast)	10—13	3·5—5·3	9·5—9·7	·23—·
Steel (cast)	19—21	7·4—7·6	16·4—17·5	·28
Steel (mild)	22	8—8·9	16—19	·25—·
Lead	1·6	·6	4·5	·44
Glass (crown)	6·0—7·8	2·6—3·2	4·0 to 5·0	·20—·
Glass (flint)	5—6	2·3	3·7	·22—·
Phosphor bronze	12·0	4·4	12·1	·329
Silver	7·8	2·2	10·5	·37
Gold	8·0	2·77	16·5	·422
India Rubber	·05	·00015	...	·48

3. Some important temperatures

	Absolute scale in degrees	Centi... in de...
Absolute zero	0	
Boiling point of liquid helium	4·2	
Boiling point of liquid hydrogen	20·3	
Boiling point of liquid air	83	
Melting point of ice	273	
Estimated temperature of the outer layer of sun	6000	
...hottest star	25000	

6. Properties of water

Temperature °C	Density gm./cc.	Specific heat cal./gm.	Surface tension dynes/cm.	Co efficient of viscosity poise × 10^{-5}
0	·9998	1·0093	......	1793
4	1·0000	1·0047	72·92	......
10	·9997	1·0019	74·22	1309
20	·9982	·9988	72·75	101·6
30	·9956	·9976	71·18	800
40	·9921	·9973	......	657
50	·9921	·9978	......	650
60	·9980	·9987		469

7. Properties of gases

Substance	Density at N.T.P. gm./c.c.	Specific heat (Cp) cal gm.	Ratio of two Specific heat $\gamma = \frac{Cp}{Cv}$	coefficient of thermal conductivity cal. cm.$^{-1}$ Sec^{-1} °C^{-1}
Air	·001293	·241	1·402	·57
Carbon-dioxide	·001977	·201	1·306	·327
Hydrogen	·0000899	3·402	1·41	3·18
Nitrogen	·001251	·249	1·40	0·53
Oxygen	·001429	·22	1·40	0·563
Steam	·000558	·458	1·303	0·512

8. Velocity of sound in solids, liquids and gases.

Solids	Velocity at 20°C metres/sec.	Liquids	Velocity at 20°C metres/sec.	gases	Velocity at 20°C metres/sec.
Brass	3490	Mercury	1407	Air	331·7
Copper	3560	Water	1437	Carbon-dioxide	259·0
Glass	5000			water vapour	401
Iron	5130				
Steel	4990				

5. Properties of liquids

Substance	Density at 0°C gm./c. c.	Specific heat cal./gm.	Latent heat cal./gm. at normal boiling point	coefficient of cubical expansion per °C $\times 10^{-4}$	Thermal conductivity cal./cm.$^{-1}$ sec.$^{-1}$°C^{-1}	Freezing point °C at normal pressure	Boiling point °C at normal pressure	Surface tension at 20°C dynes/cm.	coefficient of viscosity at 20°C poise $\times 10^{-6}$
Alcohol (Ethyl)	·79	·58	205	11·0	4·2	−115	78·3	22·3	1192
Alcohol (Methyl)	·8[illegible]7	·60	267	12·2	5·0	−97	64·7	22·6	591
Chloroform	1·527	·23	58·5	12·6	2·88	−63	61·2	27·2	564
Ether	·736	·56	88·4	16·3	3·03	−123	34·6	18.4	264
Glycerine	1·26	·58	...	5.3	6·37	17	290	63.14	83×10^4
Mercury	13·596	·0333	68	1·82	1·97	−38·9	356·7	520	1560
Paraffin oil	·8	·52	...	9	3·6	...	...	26	...
Turpentine	·873	·42	70	9·4	3·25	−10	159	27·3	1490
Water	·9998	1·0093	538	1·5	14	0	100	73·5	1793

12. Specific resistance and temperature coefficient

Substance	Specific Resistance ohm—cm. $\times 10^{-6}$	Temperature Coefficient per °C	Substances	Specific resistance ohm—cm $\times 10^{-6}$	Temperature coefficient per°C
Copper	1'78	'0043	Brass	6—9	'0010
Iron	9—15	'0062	Constantan (Eureka)	47'0	'00002
Steel	19'9	...			
			German silver	16—40	'00044
Mercury	95'76	'00088			
			Silver	16—40	'00044
Silver	1'65	'0040	Manganin	44'5	'00001
Tungston	5'0	'0051			
			Nichrome	11'0	'00017

13. Electro-chemical equivalents

Copper	0'000329 gm.	per coulomb
Silver	0'001118 „	„
Nickel	0'000304 „	„

14. Horizontal component of earth's magnetic field (H):— It may be taken as 0'30 to 0'35 through out Rajasthan. The mean value 0'33 would more or less be correct for any place in Rajasthan.

15. A few important datas and formulae

$\pi = 3'14159$

1 Atmosphere=76 cm. of Mercury or $=10^6$ dynes.

1 Joule $=10^7$ ergs

1 Watt =1 Joule per sec

1 Horsepower=746 watts.

1 Kilo watt hour =1000 watts.

R, the gas constant $=8'305 \times 10^7$ ergs per gm mol.

1 gallon of water weighs 10 lbs. approximately.

1 Cubic ft. of water weighs 62'43 lbs.

Area of circle of radius $r = \pi r^2$

Area of a sphere of radius $r = 4\pi r^2$

Volume of a cylinder of radius r, and length $l = \pi r^2 l$

Volume of a sphere of radius r $= \frac{4}{3}\pi r^3$

Area of the curved surface of cylinder of length l & radius r =

9. Refractive indices and dispersive powers
($\lambda = 5893$ A. U. at 20 °C).

Substance	Refractive index (μ)	Dispersive power (ω)	Substance	Refractive index (μ)	Dispersive power (ω)
Canada balsam	1·530	... ...	Ether	1·352	1·017
Diamond	2·417	... ...	Glycerine	1·474	1
Crown glas	1·585	0·018	Turpentine	1·48	...
Flint glass	1·58–1·66	0·020–0·027	Water	1·333	·018
Quartz	$\mu_0 = 1·544$				

10 Emission spectra of solids and gases

Element	Principal spectral lines wave length (10^{-8}cm.) or A units	Element	Principal spectral lines wave lengths (10^{-8}cm.) or in A. units
Potassium (in flame)	4044·2 (v) 4047·2 (v) 7664·9 (r) 7702 (r)	Neon	5852·4 (y) 5881·9 (o) 6402·3 (o) 6505·6 (o)
Sodium (in flame)	D_1 5890·2 D_2 5896·2	Mercury	4046·5 (v) 4339·2 4358·2 (v) 4916 (bg) 4359 (g) 5460·7 (g) 5790 (y) 6232 (o) 6[illegible]08 (r)
Hydrogen	4101·7 (v) 4340·4 (b) 4861·4 (gb) 6562·8 (r)		

11. Resistance of wires

S.W.G. No.	Diameter in		Resistance in ohm per metre			
	mm.	inch.	Copper	Manganin	Eureka	German Silver
18	1·22	0·048	0·0148	0·361	0·405	0·193
20	0·914	0·036	0·0260	0·645	0·722	0·345
22	0·711	0·028	0·0435	1·07	1·22	0·57
24	0·559	0·022	0·070	1·73	1·93	0·92
26	0·457	0·0180	0·115	2·58	2·83	1·38
28	0·376	0·0148	0·155	4·32	4·27	2·02
30	0·351	0·0124	0·222	6·45	6·08	2·60
32	0·274	0·0108	0·293	8·13	8·07	3·63

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170						5	9	13	17	21	26	30	34	38
						0212	0253	0294	0334	0374	4	8	12	16	20	24	28	32	36
11	0414	0453	0492	0531	0569						4	8	11	16	20	23	27	31	35
						0607	0645	0682	0719	0755	4	7	11	15	18	22	26	29	33
12	0792	0828	0864	0899	0934						3	7	11	14	18	21	25	28	32
						0969	1004	1038	1072	1106	3	7	10	14	17	20	24	27	31
13	1139	1173	1206	1239	1271						3	6	10	13	16	19	23	26	29
						1303	1335	1367	1399	1430	3	7	10	13	16	19	22	25	29
14	1461	1492	1523	1553	1584						3	6	9	12	15	19	22	25	28
						1614	1644	1673	1703	1732	3	6	9	12	14	17	20	23	26
15	1761	1790	1818	1847	1875						3	6	9	11	14	17	20	23	26
						1903	1931	1959	1987	2014	3	6	8	11	14	17	19	22	25
16	2041	2068	2095	2122	2148						3	6	8	11	14	16	19	22	24
						2175	2201	2227	2253	2279	3	5	8	10	13	16	18	21	23
17	2304	2330	2355	2380	2405						3	5	8	10	13	15	18	20	23
						2430	2455	2480	2504	2529	3	5	8	10	12	15	17	20	22
18	2553	2577	2601	2625	2648						2	5	7	9	12	14	17	19	21
						2672	2695	2718	2742	2765	2	4	7	9	11	14	16	18	21
19	2788	2810	2833	2856	2878						2	4	7	9	11	13	16	18	20
						2900	2923	2945	2967	2989	2	4	6	8	11	13	15	17	19
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8

ANTILOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1 2 3	4 5 6	7 8 9
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0 0 1	1 1 1	2 2 2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0 0 1	1 1 1	2 2 2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0 0 1	1 1 1	2 2 2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0 0 1	1 1 1	2 2 2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0 1 1	1 1 2	2 2 2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0 1 1	1 1 2	2 2 2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0 1 1	1 1 2	2 2 2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0 1 1	1 1 2	2 2 2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0 1 1	1 1 2	2 2 3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0 1 1	1 1 2	2 2 3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0 1 1	1 1 2	2 2 3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0 1 1	1 2 2	2 2 3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0 1 1	1 2 2	2 2 3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0 1 1	1 2 2	2 3 3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0 1 1	1 2 2	2 3 3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0 1 1	1 2 2	2 3 3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0 1 1	1 2 2	2 3 3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0 1 1	1 2 2	2 3 3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0 1 1	1 2 2	2 3 3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0 1 1	1 2 2	3 3 3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0 1 1	1 2 2	3 3 3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0 1 1	2 2 2	3 3 3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0 1 1	2 2 2	3 3 3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0 1 1	2 2 2	3 3 4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0 1 1	2 2 2	3 3 4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1812	1816	0 1 1	2 2 2	3 3 4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0 1 1	2 2 3	3 3 4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0 1 1	2 2 3	3 3 4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0 1 1	2 2 3	3 4 4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0 1 1	2 2 3	3 4 4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0 1 1	2 2 3	3 4 4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0 1 1	2 2 3	3 4 4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0 1 1	2 2 3	3 4 4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0 1 1	2 2 3	3 4 4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1 1 2	2 3 3	4 4 5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1 1 2	2 3 3	4 4 5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1 1 2	2 3 3	4 4 5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1 1 2	2 3 3	4 4 5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1 1 2	2 3 3	4 4 5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1 1 2	2 3 3	4 5 5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1 1 2	2 3 4	4 5 5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1 1 2	2 3 4	4 5 5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1 1 2	2 3 4	4 5 6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1 1 2	3 3 4	4 5 6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1 1 2	3 3 4	4 5 6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1 1 2	3 3 4	5 5 6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1 1 2	3 3 4	5 5 6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1 1 2	3 3 4	5 5 6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1 1 2	3 4 4	5 6 6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1 1 2	3 4 4	5 6 6

	0	1	2	3	4	5	6	7	8	9	123	456	789
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1 2 3	3 4 5	6 7 8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1 2 3	3 4 5	6 7 8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1 2 2	3 4 5	6 7 7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1 2 2	3 4 5	6 6 7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1 2 2	3 4 5	6 6 7
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1 2 2	3 4 5	5 6 7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1 2 2	3 4 5	5 6 7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1 2 2	3 4 5	5 6 7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1 1 2	3 4 4	5 6 7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1 1 2	3 4 4	5 6 7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1 1 2	3 4 4	5 6 6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1 1 2	3 4 4	5 6 6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1 1 2	3 3 4	5 6 6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1 1 2	3 3 4	5 5 6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1 1 2	3 3 4	5 5 6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1 1 2	3 3 4	5 5 6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1 1 2	3 3 4	5 5 6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1 1 2	3 3 4	5 5 6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1 1 2	3 3 4	4 5 6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1 1 2	2 3 4	4 5 6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1 1 2	2 3 4	4 5 6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1 1 2	2 3 4	4 5 5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1 1 2	2 3 4	4 5 5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1 1 2	2 3 4	4 5 5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1 1 2	2 3 4	4 5 5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1 1 2	2 3 3	4 5 5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1 1 2	2 3 3	4 5 5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1 1 2	2 3 3	4 4 5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1 1 2	2 3 3	4 4 5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1 1 2	2 3 3	4 4 5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1 1 2	2 3 3	4 4 5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1 1 2	2 3 3	4 4 5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1 1 2	2 3 3	4 4 5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1 1 2	2 3 3	4 4 5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1 1 2	2 3 3	4 4 5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1 1 2	2 3 3	4 4 5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1 1 2	2 3 3	4 4 5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0 1 1	2 2 3	3 4 4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0 1 1	2 2 3	3 4 4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0 1 1	2 2 3	3 4 4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0 1 1	2 2 3	3 4 4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0 1 1	2 2 3	3 4 4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0 1 1	2 2 3	3 4 4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0 1 1	2 2 3	3 4 4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0 1 1	2 2 3	3 4 4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0 1 1	2 2 3	3 4 4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0 1 1	2 2 3	3 4 4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0 1 1	2 2 3	3 4 4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0 1 1	2 2 3	3 4 4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0 1 1	2 2 3	3 3 4

NATURAL SINES

Degrees	0' 0°·0	6' 0°·1	12' 0°·2	18' 0°·3	24' 0°·4	30' 0°·5	36' 0°·6	42' 0°·7	48' 0°·8	54' 0°·9	1	2	3	4	5
0	·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	·0349	0366	0384	0401	0419	0436	0454	0471	0488	0506	3	6	9	12	15
3	·0523	0541	0558	0576	0593	0610	0628	0645	0663	0680	3	6	9	12	15
4	·0698	0715	0732	0750	0767	0785	0802	0819	0837	0854	3	6	9	12	15
5	·0872	0889	0906	0924	0941	0958	0976	0993	1011	1028	3	6	9	12	14
6	·1045	1063	1080	1097	1115	1132	1149	1167	1184	1201	3	6	9	12	14
7	·1219	1236	1253	1271	1288	1305	1323	1340	1357	1374	3	6	9	12	14
8	·1392	1409	1426	1444	1461	1478	1495	1513	1530	1547	3	6	9	12	14
9	·1564	1582	1599	1616	1633	1650	1668	1685	1702	1719	3	6	9	12	14
10	·1736	1754	1771	1788	1805	1822	1840	1857	1874	1891	3	6	9	12	14
11	·1908	1925	1942	1959	1977	1994	2011	2028	2045	2062	3	6	9	11	14
12	·2079	2096	2113	2130	2147	2164	2181	2198	2215	2233	3	6	9	11	14
13	·2250	2267	2284	2300	2317	2334	2351	2368	2385	2402	3	6	8	11	14
14	·2419	2436	2453	2470	2487	2504	2521	2538	2554	2571	3	6	8	11	14
15	·2588	2605	2622	2639	2656	2672	2689	2706	2723	2740	3	6	8	11	14
16	·2756	2773	2790	2807	2823	2840	2857	2874	2890	2907	3	6	8	11	14
17	·2924	2940	2957	2974	2990	3007	3024	3040	3057	3074	3	6	8	11	14
18	·3090	3107	3123	3140	3156	3173	3190	3206	3223	3239	3	6	8	11	14
19	·3256	3272	3289	3305	3322	3338	3355	3371	3387	3404	3	5	8	11	14
20	·3420	3437	3453	3469	3486	3502	3518	3535	3551	3567	3	5	8	11	14
21	·3584	3600	3616	3633	3649	3665	3681	3697	3714	3730	3	5	8	11	14
22	·3746	3762	3778	3795	3811	3827	3843	3859	3875	3891	3	5	8	11	14
23	·3907	3923	3939	3955	3971	3987	4003	4019	4035	4051	3	5	8	11	14
24	·4067	4083	4099	4115	4131	4147	4163	4179	4195	4210	3	5	8	11	13
25	·4226	4242	4258	4274	4289	4305	4321	4337	4352	4368	3	5	8	11	13
26	·4384	4399	4415	4431	4446	4462	4478	4493	4509	4524	3	5	8	10	13
27	·4540	4555	4571	4586	4602	4617	4633	4648	4664	4679	3	5	8	10	13
28	·4695	4710	4726	4741	4756	4772	4787	4802	4818	4833	3	5	8	10	13
29	·4848	4863	4879	4894	4909	4924	4939	4955	4970	4985	3	5	8	10	13
30	·5000	5015	5030	5045	5060	5075	5090	5105	5120	5135	3	5	8	10	13
31	·5150	5165	5180	5195	5210	5225	5240	5255	5270	5284	2	5	7	10	12
32	·5299	5314	5329	5344	5358	5373	5388	5402	5417	5432	2	5	7	10	12
33	·5446	5461	5476	5490	5505	5519	5534	5548	5563	5577	2	5	7	10	12
34	·5592	5606	5621	5635	5650	5664	5678	5693	5707	5721	2	5	7	10	12
35	·5736	5750	5764	5779	5793	5807	5821	5835	5850	5864	2	5	7	10	12
36	·5878	5892	5906	5920	5934	5948	5962	5976	5990	6004	2	5	7	9	11
37	·6018	6032	6046	6060	6074	6088	6101	6115	6129	6143	2	5	7	9	11
38	·6157	6170	6184	6198	6211	6225	6239	6252	6266	6280	2	5	7	9	11
39	·6293	6307	6320	6334	6347	6361	6374	6388	6401	6414	2	4	7	9	11
40	·6428	6441	6455	6468	6481	6494	6508	6521	6534	6547	2	4	7	9	11
41	·6561	6574	6587	6600	6613	6626	6639	6652	6665	6678	2	4	7	9	11
42	·6691	6704	6717	6730	6743	6756	6769	6782	6794	6807	2	4	6	9	11
43	·6820	6833	6845	6858	6871	6884	6896	6909	6921	6934	2	4	6	8	11
44	·6947	6959	6972	6984	6997	7009	7022	7034	7046	7059	2	4	6	8	10

(Mean Differences: columns 1–5)

RECIPROCALS OF NUMBERS FROM 1 TO 10

[Numbers in the Differences columns to be subtracted, not added.]

	0	1	2	3	4	5	6	7	8	9	Mean Differences 1 2 3	4 5 6	7 8 9
5·5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	111	[illegible]	[illegible]
5·6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5·7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5·8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5·9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6·0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1645	1641	[illegible]	[illegible]	[illegible]
6·1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6·2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1612	1610	[illegible]	[illegible]	[illegible]
6·3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1577	1567	1565	001	111	[illegible]
6·4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1546	1543	1541	001	111	221
6·5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1520	[illegible]	1517	001	111	222
6·6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1497	001	111	222
6·7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1477	1473	1473	001	111	222
6·8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1451	1451	001	111	222
6·9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1435	1433	1431	001	111	222
7·0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1416	1414	[illegible]	1410	001	111	122
7·1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	001	111	122
7·2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1371	1371	001	111	122
7·3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1357	1355	1353	001	111	122
7·4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1339	1337	1335	001	111	112
7·5	1333	1332	1330	1328	1326	1325	1323	1321	1319	1318	001	111	222
7·6	1316	1314	1312	1311	1309	1307	1305	1304	1302	1300	001	111	222
7·7	1299	1297	1295	1294	1292	1290	1289	1287	1285	1284	000	111	111
7·8	·1282	1280	1279	1277	1276	1274	1272	1271	1269	1267	000	111	111
7·9	·1266	1264	1263	1261	1259	1258	1256	1255	1253	1252	000	111	111
8·0	·1250	1248	1247	1245	1244	1242	1241	1239	1238	1236	000	111	111
8·1	·1235	1233	1232	1230	1229	1227	1225	1224	1222	1221	000	111	111
8·2	·1220	1218	1217	1215	1214	1212	1211	1209	1208	1206	000	111	111
8·3	·1205	1203	1202	1200	1199	1198	1196	1195	1193	1192	000	111	111
8·4	·1190	1189	1188	1186	1185	1183	1182	1181	1179	1178	000	111	111
8·5	·1176	1175	1174	1172	1171	1170	1168	1167	1166	1164	000	111	111
8·6	·1163	1161	1160	1159	1157	1156	1155	1153	1152	1151	000	111	111
8·7	·1149	1148	1147	1145	1144	1143	1142	1140	1139	1138	000	111	111
8·8	·1136	1135	1134	1133	1131	1130	1129	1127	1126	1125	000	111	111
8·9	·1124	1122	1121	1120	1119	1117	1116	1115	1114	1112	000	111	111
9·0	·1111	1110	1109	1107	1106	1105	1104	1103	1101	1100	000	111	111
9·1	·1099	1098	1096	1095	1094	1093	1092	1091	1089	1088	000	011	111
9·2	·1087	1086	1085	1083	1082	1081	1080	1079	1078	1076	000	011	111
9·3	·1075	1074	1073	1072	1071	1070	1068	1067	1066	1065	000	011	111
9·4	·1064	1063	1062	1060	1059	1058	1057	1056	1055	1054	000	011	111
9·5	·1053	1052	1050	1049	1048	1047	1046	1045	1044	1043	000	011	111
9·6	·1042	1041	1040	1038	1037	1036	1035	1034	1033	1032	000	011	111
9·7	·1031	1030	1029	1028	1027	1026	1025	1024	1022	1021	000	011	111
9·8	·1020	1019	1018	1017	1016	1015	1014	1013	1012	1011	000	011	111
9·9	·1010	1009	1008	1007	1006	1005	1004	1003	1002	1001	000	011	111

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences 1	2	3	4	5
0	·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	·0349	0367	0384	0402	0419	0437	0454	0472	0489	0507	3	6	9	12	15
3	·0524	0542	0559	0577	0594	0612	0629	0647	0664	0682	3	6	9	12	15
4	·0699	0717	0734	0752	0769	0787	0805	0822	0840	0857	3	6	9	12	15
5	·0875	0892	0910	0928	0945	0963	0981	0998	1016	1033	3	6	9	12	15
6	·1051	1069	1086	1104	1122	1139	1157	1175	1192	1210	3	6	9	12	15
7	·1228	1246	1263	1281	1299	1317	1334	1352	1370	1388	3	6	9	12	15
8	·1405	1423	1441	1459	1477	1495	1512	1530	1548	1566	3	6	9	12	15
9	·1584	1602	1620	1638	1655	1673	1691	1709	1727	1745	3	6	9	12	15
10	·1763	1781	1799	1817	1835	1853	1871	1890	1908	1926	3	6	9	12	15
11	·1944	1962	1980	1998	2016	2035	2053	2071	2089	2107	3	6	9	12	15
12	·2126	2144	2162	2180	2199	2217	2235	2254	2272	2290	3	6	9	12	15
13	·2309	2327	2345	2364	2382	2401	2419	2438	2456	2475	3	6	9	12	15
14	·2493	2512	2530	2549	2568	2586	2605	2623	2642	2661	3	6	9	12	15
15	·2679	2698	2717	2736	2754	2773	2792	2811	2830	2849	3	6	9	12	16
16	·2867	2886	2905	2924	2943	2962	2981	3000	3019	3038	3	6	9	13	16
17	·3057	3076	3096	3115	3134	3153	3172	3191	3211	3230	3	6	9	13	16
18	·3249	3269	3288	3307	3327	3346	3365	3385	3404	3424	3	6	10	13	16
19	·3443	3463	3482	3502	3522	3541	3561	3581	3600	3620	3	6	10	13	16
20	·3640	3659	3679	3699	3719	3739	3759	3779	3799	3819	3	7	10	13	16
21	·3839	3859	3879	3899	3919	3939	3959	3979	4000	4020	3	7	10	13	17
22	·4040	4061	4081	4101	4122	4142	4163	4183	4204	4224	3	7	10	13	17
23	·4245	4265	4286	4307	4327	4348	4369	4390	4411	4431	3	7	10	14	17
24	·4452	4473	4494	4515	4536	4557	4578	4599	4621	4642	3	7	10	14	17
25	·4663	4684	4706	4727	4748	4770	4791	4813	4834	4856	4	7	11	14	18
26	·4877	4899	4921	4942	4964	4986	5008	5029	5051	5073	4	7	11	14	18
27	·5095	5117	5139	5161	5184	5206	5228	5250	5272	5295	4	7	11	15	18
28	·5317	5340	5362	5384	5407	5430	5452	5475	5498	5520	4	7	11	15	18
29	·5543	5566	5589	5612	5635	5658	5681	5704	5727	5750	4	8	11	15	19
30	·5774	5797	5820	5844	5867	5890	5914	5938	5961	5985	4	8	12	15	19
31	·6009	6032	6056	6080	6104	6128	6152	6176	6200	6224	4	8	12	16	20
32	·6249	6273	6297	6322	6346	6371	6395	6420	6445	6469	4	8	12	16	20
33	·6494	6519	6544	6569	6594	6619	6644	6669	6694	6720	4	8	12	16	20
34	·6745	6771	6796	6822	6847	6873	6899	6924	6950	6976	4	9	13	17	21
35	·7002	7028	7054	7080	7107	7133	7159	7186	7212	7239	4	9	13	17	22
36	·7265	7292	7319	7346	7373	7400	7427	7454	7481	7508	4	9	13	18	22
37	·7536	7563	7590	7618	7646	7673	7701	7729	7757	7785	5	9	14	18	23
38	·7813	7841	7869	7898	7926	7954	7983	8012	8040	8069	5	9	14	18	23
39	·8098	8127	8156	8185	8214	8243	8273	8302	8332	8361	5	9	14	19	24
40	·8391	8421	8451	8481	8511	8541	8571	8601	8632	8662	5	10	15	20	25
41	·8693	8724	8754	8785	8816	8847	8878	8910	8941	8972	5	10	15	20	25
42	·9004	9036	9067	9099	9131	9163	9195	9228	9260	9293	5	10	16	21	26
43	·9325	9358	9391	9424	9457	9490	9523	9556	9590	9623	5	11	16	21	27
44	·9657	9691	9725	9759	9793	9827	9861	9896	9930	9965	6	11	17	23	28

NATURAL SINES

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences 1	2	3	4	5
45	·7071	7083	7096	7108	7120	7133	7145	7157	7169	7181	2	4	6	8	10
46	·7193	7206	7218	7230	7242	7254	7266	7278	7290	7302	2	4	6	8	10
47	·7314	7325	7337	7349	7361	7373	7385	7396	7408	7420	2	4	6	8	10
48	·7431	7443	7455	7466	7478	7490	7501	7513	7524	7536	2	4	6	8	10
49	·7547	7559	7570	7581	7593	7604	7615	7627	7638	7649	2	4	6	8	9
50	·7660	7672	7683	7694	7705	7716	7727	7738	7749	7760	2	4	6	7	9
51	·7771	7782	7793	7804	7815	7826	7837	7848	7859	7869	2	4	5	7	9
52	·7880	7891	7902	7912	7923	7934	7944	7955	7965	7976	2	4	5	7	9
53	·7986	7997	8007	8018	8028	8039	8049	8059	8070	8080	2	3	5	7	9
54	·8090	8100	8111	8121	8131	8141	8151	8161	8171	8181	2	3	5	7	8
55	·8192	8202	8211	8221	8231	8241	8251	8261	8271	8281	2	3	5	7	8
56	·8290	8300	8310	8320	8329	8339	8348	8358	8368	8377	2	3	5	6	8
57	·8387	8396	8406	8415	8425	8434	8443	8453	8462	8471	2	3	5	6	8
58	·8480	8490	8499	8508	8517	8526	8536	8545	8554	8563	2	3	5	6	8
59	·8572	8581	8590	8599	8607	8616	8625	8634	8643	8652	1	3	4	6	7
60	·8660	8669	8678	8686	8695	8704	8712	8721	8729	8738	1	3	4	6	7
61	·8746	8755	8763	8771	8780	8788	8796	8805	8813	8821	1	3	4	6	7
62	·8829	8838	8846	8854	8862	8870	8878	8886	8894	8902	1	3	4	5	7
63	·8910	8918	8926	8934	8942	8949	8957	8965	8973	8980	1	3	4	5	6
64	·8988	8996	9003	9011	9018	9026	9033	9041	9048	9056	1	3	4	5	6
65	·9063	9070	9078	9085	9092	9100	9107	9114	9121	9128	1	2	4	5	6
66	·9135	9143	9150	9157	9164	9171	9178	9184	9191	9198	1	2	3	5	6
67	·9205	9212	9219	9225	9232	9239	9245	9252	9259	9265	1	2	3	4	6
68	·9272	9278	9285	9291	9298	9304	9311	9317	9323	9330	1	2	3	4	5
69	·9336	9342	9348	9354	9361	9367	9373	9379	9385	9391	1	2	3	4	5
70	·9397	9403	9409	9415	9421	9426	9432	9438	9444	9449	1	2	3	4	5
71	·9455	9461	9466	9472	9478	9483	9489	9494	9500	9505	1	2	3	4	5
72	·9511	9516	9521	9527	9532	9537	9542	9548	9553	9558	1	2	3	3	4
73	·9563	9568	9573	9578	9583	9588	9593	9598	9603	9608	1	2	2	3	4
74	·9613	9617	9622	9627	9632	9636	9641	9646	9650	9655	1	2	2	3	4
75	·9659	9664	9668	9673	9677	9681	9686	9690	9694	9699	1	1	2	3	4
76	·9703	9707	9711	9715	9720	9724	9728	9732	9736	9740	1	1	2	3	3
77	·9744	9748	9751	9755	9759	9763	9767	9770	9774	9778	1	1	2	3	3
78	·9781	9785	9789	9792	9796	9799	9803	9806	9810	9813	1	1	2	2	3
79	·9816	9820	9823	9826	9829	9833	9836	9839	9842	9845	1	1	2	2	3
80	·9848	9851	9854	9857	9860	9863	9866	9869	9871	9874	0	1	1	2	2
81	·9877	9880	9882	9885	9888	9890	9893	9895	9898	9900	0	1	1	2	2
82	·9903	9905	9907	9910	9912	9914	9917	9919	9921	9923	0	1	1	2	2
83	·9925	9928	9930	9932	9934	9936	9938	9940	9942	9943	0	1	1	1	2
84	·9945	9947	9949	9951	9952	9954	9956	9957	9959	9960	0	1	1	1	1
85	·9962	9963	9965	9966	9968	9969	9971	9972	9973	9974	0	0	1	1	1
86	·9976	9977	9978	9979	9980	9981	9982	9983	9984	9985	0	0	1	1	1
87	·9986	9987	9988	9989	9990	9990	9991	9992	9993	9993	0	0	0	1	1
88	·9994	9995	9995	9996	9996	9997	9997	9997	9998	9998	0	0	0	0	0
89	·9998	9999	9999	9999	9999	1·000	1·000	1·000	1·000	1·000	0	0	0	0	0

NATURAL COSINES

(Numbers in difference columns to be subtracted, not added.)

Degrees	0' 0°·0	6' 0°·1	12' 0°·2	18' 0°·3	24' 0°·4	30' 0°·5	36' 0°·6	42' 0°·7	48' 0°·8	54' 0°·9	Mean Differences 1'	2'	3'	4'	5'
0	1·000	1·000	1·000	1·000	1·000	1·000	·9999	·9999	·9999	·9999	0	0	0	0	0
1	·9998	9998	9998	9997	9997	9997	9996	9996	9995	9995	0	0	0	0	0
2	·9994	9993	9993	9992	9991	9990	9990	9989	9988	9987	0	0	0	0	0
3	·9986	9985	9984	9983	9982	9981	9980	9979	9978	9977	0	0	0	1	1
4	·9976	9974	9973	9972	9971	9969	9968	9966	9965	9963	0	0	1	1	1
5	·9962	9960	9959	9957	9956	9954	9952	9951	9949	9947	0	1	1	1	1
6	·9945	9943	9942	9940	9938	9936	9934	9932	9930	9928	0	1	1	1	2
7	·9925	9923	9921	9919	9917	9914	9912	9910	9907	9905	0	1	1	1	2
8	·9903	9900	9898	9895	9893	9890	9888	9885	9882	9880	0	1	1	2	2
9	·9877	9874	9871	9869	9866	9863	9860	9857	9854	9851	0	1	1	2	2
10	·9848	9845	9842	9839	9836	9833	9829	9826	9823	9820	1	1	2	2	3
11	·9816	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	·9781	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	·9744	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	·9703	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	·9659	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	·9613	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	·9563	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	·9511	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19	·9455	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	·9397	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21	·9336	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22	·9272	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23	·9205	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24	·9135	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	·9063	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
26	·8988	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
27	·8910	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
28	·8829	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
29	·8746	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30	·8660	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
31	·8572	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
32	·8480	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
33	·8387	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
34	·8290	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
35	·8192	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
36	·8090	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
37	·7986	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
38	·7880	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39	·7771	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
40	·7660	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
41	·7547	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
42	·7431	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
43	·7314	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
44	·7193	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
45	·7071	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences 1	2	3
45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	12	18
46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	12	18
47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	13	19
48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	13	20
49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	14	21
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	14	22
51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8	15	23
52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8	16	24
53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8	16	25
54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9	17	26
55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9	18	27
56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	19	29
57	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	20	30
58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11	21	32
59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11	23	34
60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12	24	36
61	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13	26	38
62	[illegible]	[illegible]	[illegible]	[illegible]	9128	9210	9292	9375	9458	9542	14	27	41
63	[illegible]	[illegible]	[illegible]	[illegible]	9970	2·0057	2·0145	2·0233	2·0323	2·0413	15	29	44
64	2·0503	0594	0686	0778	0872	0965	1060	1155	1251	1348	16	31	47
65	2·1445	1543	1642	1742	1842	1943	2045	2148	2251	2355	17	34	51
66	2·2460	2566	2673	2781	2889	2998	3109	3220	3332	3445	18	37	55
67	2·3559	3673	3789	3906	4023	4142	4262	4383	4504	4627	20	40	60
68	2·4751	4876	5002	5129	5257	5386	5517	5649	5782	5916	22	43	65
69	2·6051	6187	6325	6464	6605	6746	6889	7034	7179	7326	24	47	71
70	2·7475	7625	7776	7929	8083	8239	8397	8556	8716	8878	26	52	78
71	2·9042	9208	9375	9544	9714	9887	3·0061	3·0237	3·0415	3·0595	29	58	87
72	3·0777	0961	1146	1334	1524	1716	1910	2106	2305	2506	32	64	96
73	3·2709	2914	3122	3332	3544	3759	3977	4197	4420	4646	36	72	108
74	3·4874	5105	5339	5576	5816	6059	6305	6554	6806	7062	41	82	122
75	3·7321	7583	7848	8118	8391	8667	8947	9232	9520	9812	46	93	139
76	4·0108	0408	0713	1022	1335	1653	1976	2303	2635	2972	53	107	160
77	4·3315	3662	4015	4373	4737	5107	5483	5864	6252	6646			
78	4·7046	7453	7867	8288	8716	9152	9594	5·0045	5·0504	5·0970			
79	5·1446	1929	2422	2924	3435	3955	4486	5026	5578	6140			
80	5·6713	7297	7894	8502	9124	9758	6·0405	6·1066	6·1742	6·2432			
81	6·3138	3859	4596	5350	6122	6912	7720	8548	9395	7·0264			
82	7·1154	2066	3002	3962	4947	5958	6996	8062	9158	8·0285			
83	8·1443	2636	3863	5126	6427	7769	9152	9·0579	9·2052	9·3572			
84	9·5144	9·677	9·845	10·02	10·20	10·39	10·58	10·78	10·99	11·20			
85	11·43	11·66	11·91	12·16	12·43	12·71	13·00	13·30	13·62	13·95			
86	14·30	14·67	15·06	15·46	15·89	16·35	16·83	17·34	17·89	18·46			
87	19·08	19·74	20·45	21·20	22·02	22·90	23·86	24·90	26·03	27·27			
88	28·64	30·14	31·82	33·69	35·80	38·19	40·92	44·07	47·74	52·08			
89	57·29	63·66	71·62	81·85	95·49	114·6	143·2	191·0	286·5	573·0			

Mean differences [illegible] to be [illegible] accurate.

NATURAL COSINES

(Numbers in difference columns to be subtracted, not added.)

Degrees	0' 0°·0	6' 0°·1	12' 0°·2	18' 0°·3	24' 0°·4	30' 0°·5	36' 0°·6	42' 0°·7	48' 0°·8	54' 0°·9	Mean Differences 1	2	3	4	5
45	·7071	7059	7046	7034	7022	7009	6997	6984	6972	6959	2	4	6	8	10
46	·6947	6934	6921	6909	6896	6884	6871	6858	6845	6833	2	4	6	8	11
47	·6820	6807	6794	6782	6769	6756	6743	6730	6717	6704	2	4	6	9	11
48	·6691	6678	6665	6652	6639	6626	6613	6600	6587	6574	2	4	7	9	11
49	·6561	6547	6534	6521	6508	6494	6481	6468	6455	6441	2	4	7	9	11
50	·6428	6414	6401	6388	6374	6361	6347	6334	6320	6307	2	4	7	9	11
51	·6293	6280	6266	6252	6239	6225	6211	6198	6184	6170	2	5	7	9	11
52	·6157	6143	6129	6115	6101	6088	6074	6060	6046	6032	2	5	7	9	12
53	·6018	6004	5990	5976	5962	5948	5934	5920	5906	5892	2	5	7	9	12
54	·5878	5864	5850	5835	5821	5807	5793	5779	5764	5750	2	5	7	9	12
55	·5736	5721	5707	5693	5678	5664	5650	5635	5621	5606	2	5	7	10	12
56	·5592	5577	5563	5548	5534	5519	5505	5490	5476	5461	2	5	7	10	12
57	·5446	5432	5417	5402	5388	5373	5358	5344	5329	5314	2	5	7	10	12
58	·5299	5284	5270	5255	5240	5225	5210	5195	5180	5165	2	5	7	10	12
59	·5150	5135	5120	5105	5090	5075	5060	5045	5030	5015	3	5	8	10	13
60	·5000	4985	4970	4955	4939	4924	4909	4894	4879	4863	3	5	8	10	13
61	·4848	4833	4818	4802	4787	4772	4756	4741	4726	4710	3	5	8	10	13
62	·4695	4679	4664	4648	4633	4617	4602	4586	4571	4555	3	5	8	10	13
63	·4540	4524	4509	4493	4478	4462	4446	4431	4415	4399	3	5	8	10	13
64	·4384	4368	4352	4337	4321	4305	4289	4274	4258	4242	3	5	8	11	13
65	·4226	4210	4195	4179	4163	4147	4131	4115	4099	4083	3	5	8	11	13
66	·4067	4051	4035	4019	4003	3987	3971	3955	3939	3923	3	5	8	11	14
67	·3907	3891	3875	3859	3843	3827	3811	3795	3778	3762	3	5	8	11	14
68	·3746	3730	3714	3697	3681	3665	3649	3633	3616	3600	3	5	8	11	14
69	·3584	3567	3551	3535	3518	3502	3486	3469	3453	3437	3	5	8	11	14
70	·3420	3404	3387	3371	3355	3338	3322	3305	3289	3272	3	5	8	11	14
71	·3256	3239	3223	3206	3190	3173	3156	3140	3123	3107	3	6	8	11	14
72	·3090	3074	3057	3040	3024	3007	2990	2974	2957	2940	3	6	8	11	14
73	·2924	2907	2890	2874	2857	2840	2823	2807	2790	2773	3	6	8	11	14
74	·2756	2740	2723	2706	2689	2672	2656	2639	2622	2605	3	6	8	11	14
75	·2588	2571	2554	2538	2521	2504	2487	2470	2453	2436	3	6	8	11	14
76	·2419	2402	2385	2368	2351	2334	2317	2300	2284	2267	3	6	8	11	14
77	·2250	2233	2215	2198	2181	2164	2147	2130	2113	2096	3	6	9	11	14
78	·2079	2062	2045	2028	2011	1994	1977	1959	1942	1925	3	6	9	11	14
79	·1908	1891	1874	1857	1840	1822	1805	1788	1771	1754	3	6	9	11	14
80	·1736	1719	1702	1685	1668	1650	1633	1616	1599	1582	3	6	9	12	14
81	·1564	1547	1530	1513	1495	1478	1461	1444	1426	1409	3	6	9	12	14
82	·1392	1374	1357	1340	1323	1305	1288	1271	1253	1236	3	6	9	12	14
83	·1219	1201	1184	1167	1149	1132	1115	1097	1080	1063	3	6	9	12	14
84	·1045	1028	1011	0993	0976	0958	0941	0924	0906	0889	3	6	9	12	14
85	·0872	0854	0837	0819	0802	0785	0767	0750	0732	0715	3	6	9	12	15
86	·0698	0680	0663	0645	0628	0610	0593	0576	0558	0541	3	6	9	12	15
87	·0523	0506	0488	0471	0454	0436	0419	0401	0384	0366	3	6	9	12	15
88	·0349	0332	0314	0297	0279	0262	0244	0227	0209	0192	3	6	9	12	15
89	·0175	0157	0140	0122	0105	0087	0070	0052	0035	0017	3	6	9	12	15
90	·0000														